CANADIAN JOURNAL OF RESEARCH

VOLUME 17 JANUARY, 1939 NUMBER 1

CONTENTS

SEC. C.—BOTANICAL SCIENCES

Page

Evaporation in Agricultural Meteorology—*T. Alty* - - - - 1

Agricultural Meteorology: Some Characteristics of Winds in Alberta and Saskatchewan—*J. W. Hopkins* - - - - - 4

Varietal Differences in Barleys and Malts. V. Wort Nitrogen and Malt Extract and Their Correlations with Barley Nitrogen Fractions—*J. A. Anderson, C. A. Ayre and W. O. S. Meredith* - - - - - - - - - - - - - - - 25

SEC. D.—ZOOLOGICAL SCIENCES

Colour of Meat. I. Apparatus for its Measurement, and Relation between pH and Colour—*C. A. Winkler* - - - 1

Tenderness of Meat. I. A Recording Apparatus for its Estimation, and Relation between pH and Tenderness—*C. A. Winkler* - - - - - - - - - - - - - - - - 8

Studies with a Deficient Ration for Sheep. I. Effect of Various Supplements. II. Effect of a Cobalt Supplement—*J. E. Bowstead and J. P. Sackville* - - - - - - - - - 15

NATIONAL RESEARCH COUNCIL
OTTAWA, CANADA

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	Annual	*Single Copy*
A and B	$ 2.50	$ 0.50
C and D	2.50	0.50
Four sections, complete	4.00	—

The Canadian Journal of Research is published by the National Research Council of Canada under authority of the Chairman of the Committee of the Privy Council on Scientific and Industrial Research. All correspondence should be addressed:

National Research Council, Ottawa, Canada.

Reprinted in entirety by photo-offset from the original issue.

Canadian Journal of Research

Issued by THE NATIONAL RESEARCH COUNCIL OF CANADA

VOL. 17, SEC. C. JANUARY, 1939 NUMBER 1

EVAPORATION IN AGRICULTURAL METEOROLOGY[1]

BY T. ALTY[2]

The rate of evaporation from a free water surface and its relation to other meteorological factors are of considerable importance to agricultural science. The correlation of evaporation with air temperature, vapour pressure, and wind velocity has been examined by Hopkins and James (1), who showed that while, in general, high average temperatures were associated with high evaporation, the correlation between the two quantities was very poor. The object of the present note is to emphasize the fact that in order to relate the rate of evaporation to other meteorological factors, the temperature of the evaporating liquid surface must be known, and that the measurement of such temperatures at agricultural meteorological stations would be valuable.

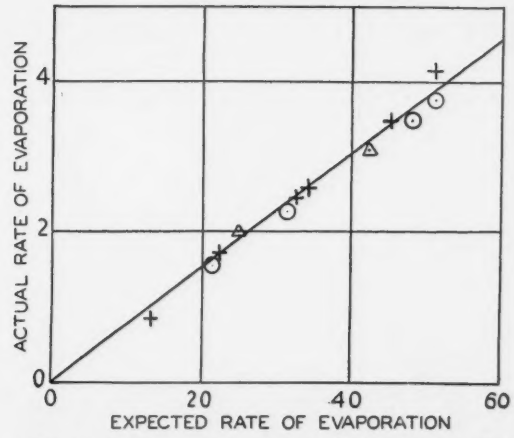

FIG. 1. *Relation between expected (E_1) and actual (E_2) rates of evaporation of water, in arbitrary units.* +, *air and water at same temperature.* ○, *water warmer than air.* △, *air warmer than water.*

On theoretical grounds the rate of evaporation E under any given conditions should be directly proportional to the quantity $(P - p)$, where P is the saturated vapour pressure at the temperature of the surface of the evapor-

[1] *Manuscript received July 11, 1938.*
Contribution from Laboratory of Applied Physics, University of Glasgow, Scotland.

[2] *Cargill Professor, University of Glasgow.*

ating liquid and p is the pressure of the vapour actually present in the air. In the course of other work, an opportunity arose of examining experimentally the relation between E and $(P - p)$. A stream of dry air was drawn at constant speed over the evaporating surface. In each experiment the temperature of the liquid in the actual evaporating surface was measured by means of a thermocouple immersed in the surface; a second thermocouple enabled the air temperature just above the evaporating liquid to be measured. These temperatures were measured at regular intervals during the experiment. As they varied somewhat during the course of the experiment, $(P - p)$ would change. However, if dE_1 is the amount of evaporation to be expected in a short time dt, then

$$dE_1 = k(P - p)dt$$

and

$$E_1 = k\int_0^T (P - p)dt$$

where k is a constant and T is the duration of the experiment.

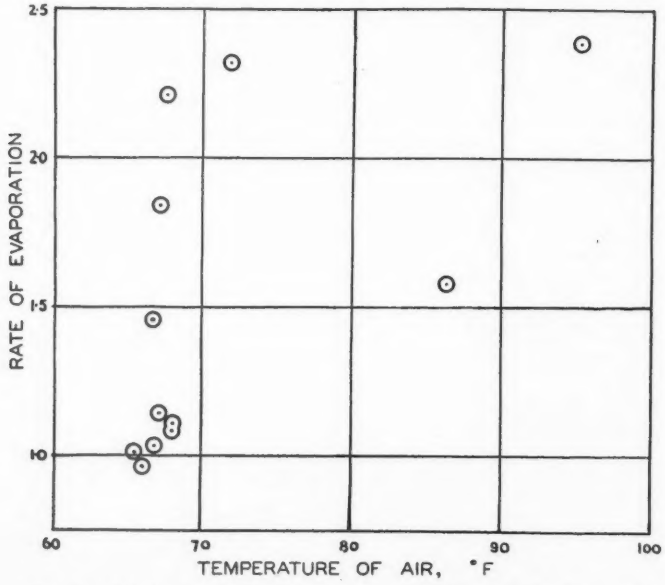

FIG. 2. *Relation between air temperature and rate of evaporation of water, in arbitrary units.*

This integral was evaluated graphically and the result plotted against the actual rate (E_2) of evaporation as determined directly by weighing. The results are shown in Fig. 1. It will be seen that there is an excellent linear

relation between E_1 and E_2. Since in evaporation experiments in the open air the liquid may be either warmer or cooler than the air above it, experiments were performed with air and water originally at the same temperature (+), with the water warmer than the air (○), and with the air warmer than the water (△). Fig. 1 indicates that E_1/E_2 remains constant no matter what may be the relative temperatures of air and water.

For comparison, in Fig. 2, the rate of evaporation in these experiments is plotted against the air temperature. Clearly there is no very definite relation between these two quantities. For studies of evaporation it therefore seems very desirable that water surface temperatures should be determined as well as air temperatures. It should be noted that as the evaporation process itself cools the surface, the temperature of the latter is never equal to that of the liquid as a whole. No doubt a good approximation to the required surface temperature could be obtained by floating a thermometer horizontally in the surface.

References

1. HOPKINS, J. W. and JAMES, MABEL F. Can. J. Research, C, 13 : 191-201. 1935.

AGRICULTURAL METEOROLOGY: SOME CHARACTERISTICS OF WINDS IN ALBERTA AND SASKATCHEWAN[1]

By J. W. Hopkins[2]

Abstract

Over a period of years, the monthly mean mileage of wind per day during the six months, April to September, at four meteorological stations in central and southern Alberta and Saskatchewan is greatest in April and May, and least in July and August. In all cases the range of variation of the monthly means is considerable, being of the order of 50%. Significant correlation in the inter-annual fluctuations at the four stations is not demonstrable from the available data, but there is some indication of correlation between the mileages at a given station in successive months of the same year. During the season as a whole, northwesterly winds predominate, but in this respect also there are pronounced annual variations.

Variation in the amount of wind from day to day within months is also pronounced, and tables are presented showing for each of the six months the relative frequency of occurrence of different daily mileages.

On the whole, more wind is recorded during the daytime than at night. The hourly averages for all six months show a definite diurnal trend, the maximum being in the vicinity of 3 p.m., but the actual hourly sequence on a given day may deviate markedly from this underlying regularity. There is a slight tendency for days of above-average temperature to have a higher wind mileage, but this is a minor factor in comparison with the uncorrelated variation of both quantities.

In view of the important influence that winds may exert upon growing crops, by affecting transpiration and hence the water requirement (3, 4), as well as by mechanical damage, a statistical study has been made of wind observations for the months April to September inclusive recorded at four representative meteorological stations in central and southern Alberta and Saskatchewan. Similar studies of rainfall and temperature statistics have already been reported (1, 2). The stations in question are Lacombe (central Alberta), lat. 52° 28′ N., long. 113° 44′ W., alt. 2783 ft.; Calgary (southern Alberta), 51° 2′ N., 114° 2′ W., 3428 ft.; Battleford (central Saskatchewan) 52° 41′ N., 108° 20′ W., 1592 ft.; and Qu'Appelle (southern Saskatchewan), 50° 31′ N., 103° 56′ W., 2115 ft.

Wind mileage is recorded at three of these stations by anemometers of the three-cup type; at Lacombe an older type of four-cup instrument is in use. The height above ground at which the instruments are exposed ranges from about 25 ft. at Qu'Appelle to about 80 ft. at Calgary. In all cases the exposure is reported to be unobstructed. It requires to be noted that in April of 1931 the Calgary anemometer was removed to the local airport, since when the mileages reported have been consistently higher than those prevailing at its former location. Comparable data are available for three of these stations for a period of 14 to 16 years, but it has been ascertained that the anemometer at Lacombe was in a defective condition for some time, probably

[1] *Manuscript received November 24, 1938.*

Contribution from the Division of Biology and Agriculture, National Research Laboratories, Ottawa. Published as Paper No. 155 of the Associate Committee on Grain Research of the National Research Council of Canada and the Dominion Department of Agriculture.

[2] *Statistician, National Research Laboratories, Ottawa.*

from 1931 to 1936. Consequently, only the observations made prior to that time at this point have been included in this study.

The data used were in part extracted from the published Monthly Record of the Meteorological Service of Canada (5), and in part transcribed directly from the original record sheets in the Meteorological archives, by kind permission of Mr. J. Patterson, Controller, to whom thanks are due for making this material available.

Monthly Mileage

Table I summarizes the available records of total monthly mileage, giving the average and maximum and minimum values for the period indicated. As three of the months considered comprise 31 days, and three only 30, all comparisons have been made on the basis of monthly mean mileage per day.

TABLE I

WIND MILEAGE, 1922–1937, EXPRESSED AS MONTHLY MEAN MILEAGE PER DAY

Station*	Statistic	April	May	June	July	August	September
Lacombe	Average	198	210	193	167	144	171
	Maximum	230	234	217	201	176	218
	Minimum	146	186	178	140	123	127
Calgary	Average	194	198	185	158	165	174
	Maximum	258	272	251	233	212	222
	Minimum	140	131	139	91	100	125
Battleford	Average	237	247	215	210	187	200
	Maximum	303	307	261	314	223	261
	Minimum	111	206	163	154	135	154
Qu'Appelle	Average	241	241	212	193	195	216
	Maximum	283	287	276	256	248	256
	Minimum	188	170	157	149	176	182

* *Lacombe, 8 yr. data (1923–1930). Calgary, 15 yr. data for April, June, July and August, 16 yr. for May and September. Battleford, 15 yr. data for April, 14 yr. for other months. Qu'Appelle, 16 yr. data for all months.*

There is a similar seasonal trend in the averages for all four stations, the mean daily mileage being greatest in April and May and least in July and August. The average mileage recorded is higher for all six months at the two Saskatchewan stations than at the Alberta ones, but there is no significant difference in this respect between Lacombe and Calgary or between Battleford and Qu'Appelle. In all cases the range of variation of the monthly means over the period studied is considerable. The average range for the six months is, in terms of the unit of mean mileage per day adopted, 63 at Lacombe, 120 at Calgary, 124 at Battleford and 97 at Qu'Appelle, or 35, 67, 57 and 45%, respectively, of the mean. Clearly, therefore, there may be appreciable annual differences in the incidence of wind per month, and it

is of interest to ascertain the degree of correlation (i) between the mileage recorded at the different stations in the same month, and (ii) between the mileage at the same station in successive months.

The first of these points was investigated by the calculation of correlation coefficients. These are, of course, subject to considerable error owing to the small number of years' records available, and a fairly high value is required for statistical significance. Of the 36 coefficients thus calculated for the six possible pairings of the four stations for each month, only one exceeded the 5% point, *i.e.*, rather less than the chance expectation. It cannot therefore be asserted from these data that there is in fact any correlation in the inter-annual fluctuations of monthly wind mileage at the four stations. This is in contrast to the situation prevailing in the case of temperature and precipitation, both of which were previously found to show significant correlation between stations (1, 2).

Correlation between the total mileage recorded at individual stations in successive months of the same year was investigated by the analysis of variance procedure. The variance of the monthly totals over the period of years for which records were available at each station was separated into components due to average differences between months, average differences between years for the six months considered, and residual, as shown in Table II. (In the computations for Calgary, allowance was made for the

TABLE II

ANALYSIS OF VARIANCE OF MONTHLY WIND MILEAGE, APRIL–SEPTEMBER, 1922–1937

Variance	Lacombe†		Calgary		Battleford		Qu'Appelle	
	D.f.	Mean square	D.f.	Mean square	D.f.	Mean square	D.f.	Mean square
Between years	7	767,700*	13	549,100**	13	3,220,500**	15	1,568,100**
Between months	5	4,299,900**	5	3,618,600**	5	6,833,000**	5	6,046,000**
Residual	35	320,900	63	198,500	65	849,300	75	460,000

† *1923–1930.*

* *Exceeds mean square residual, 5% level of significance.*

** *Exceeds mean square residual, 1% level of significance.*

previously noted change in the position of the anemometer in April, 1931.) Average differences between months, due to the foregoing seasonal trend, are reflected in highly significant mean squares, but for all four stations the mean square between years also significantly exceeds the mean square residual, indicating that annual differences in the total mileage for the six months were rather larger than would be expected from the fluctuations in the individual monthly totals, had these been entirely independent in each year.

So far, attention has been confined to the total mileage of wind per month, irrespective of direction. The partition of this total between the eight points of the compass, N, NW, W, SW, etc., is, however, also recorded, and Fig. 1

shows the average values of these in the form of wind-roses. During the season as a whole, north-westerly winds clearly predominate, but in spring there is also a large mileage from the south-east. This, however, decreases as the season advances, tending to be supplanted by northerly and westerly winds at Calgary and Battleford and by southerly and westerly ones at Lacombe and Qu'Appelle.

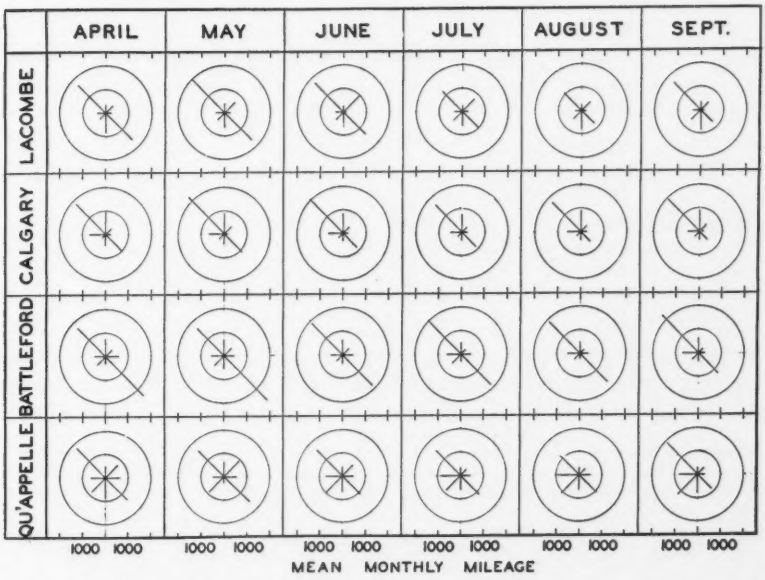

FIG. 1. *Mean monthly mileage of wind from the eight points of the compass at meteorological stations in central and southern Alberta and Saskatchewan.*

These data also permit the resultant horizontal air movement at each station each month to be computed. By the application of the ordinary rules for the composition of vectors, the mileages from the eight directions given may be expressed in terms of two components, northerly and westerly. Table III summarizes the values obtained for these, expressed as in Table I in terms of monthly mean mileage per day. There is a preponderance of positive westerly components, *i.e.*, of westerly resultant winds, at all four points, which tends to increase as the season advances, and Calgary is distinguished from the other three stations by the predominance of positive north components. Otherwise, the averages show no clear-cut tendency.

By reference to Table I it will be seen that the averages for both north and west components are small in comparison with the average total mileage. Whilst this is, of course, partly due to the occurrence of winds from opposite directions within the same month, another factor is the annual variation in

TABLE III

RESULTANT WINDS, 1922–1937, EXPRESSED AS MONTHLY MEAN MILEAGE PER DAY

Station	Statistic	April		May		June		July		August		September	
		N	W	N	W	N	W	N	W	N	W	N	W
Lacombe†	Average	− 12	6	4	8	17	− 7	− 5	3	− 7	12	2	33
	Maximum	36	54	50	43	60	37	38	32	14	39	49	46
	Minimum	− 58	− 29	−57	−58	− 16	−39	−40	−18	−47	−10	−29	1
Calgary	Average	38	30	43	38	50	38	28	25	45	34	55	44
	Maximum	85	73	76	85	85	99	77	49	24	74	90	81
	Minimum	− 21	− 5	−14	−14	− 16	10	−18	−10	70	− 4	− 5	18
Battleford	Average	− 9	− 20	−21	−18	13	3	6	16	10	14	30	39
	Maximum	74	65	30	30	54	51	54	77	48	76	59	65
	Minimum	−107	−137	−91	−72	− 30	−69	−39	−34	−22	−26	−41	20
Qu'Appelle	Average	− 6	16	−11	2	−4	27	−12	33	−22	41	−21	41
	Maximum	88	111	116	54	71	92	32	112	29	79	30	81
	Minimum	− 90	− 85	−72	−80	−100	−59	−48	−37	−72	13	−74	14

† *1923–1930.*

the values of both components for all months, which comprises many actual reversals. The effect of these annual differences on the direction and amplitude of the resultant winds is shown in more detail in Fig. 2, in which the

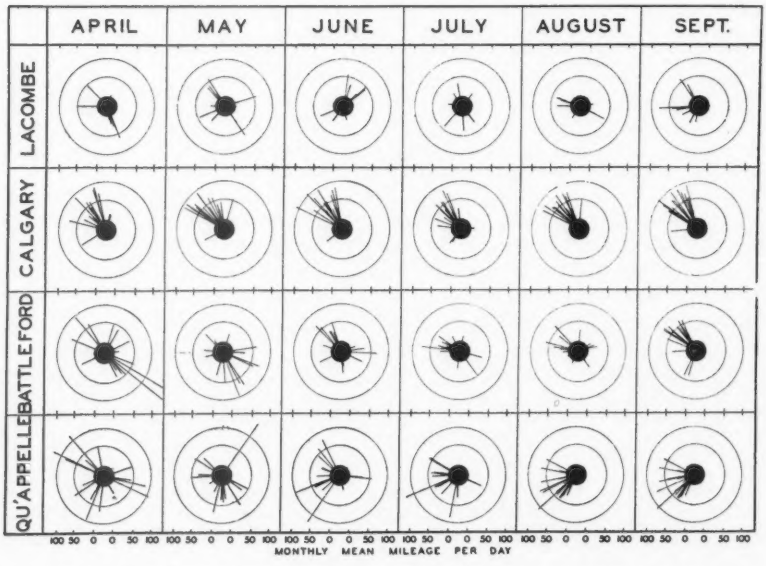

FIG. 2. *Resultant wind vectors. Length of vectors indicates mean mileage per day.*

TABLE IV

ANALYSIS OF VARIANCE OF DAILY WIND MILEAGE, 1922–1937

Station	Variance	April		May		June		July		August		September	
		D.f.	Mean sq.	D.f.	Mean sq.	D.f.	Mean sq.	D.f.	Mean sq.	D.f.	Mean sq.	D.f.	Mean sq.
Lacombe†	Inter-annual	7	18294**	7	8040	7	5940	7	17623**	7	10687**	7	20681**
	Intra-annual	219	5627	240	6652	232	6536	236	3560	240	2361	232	4647
Calgary	Inter-annual	12	5221	13	8893	13	4950	12	12769**	13	3541	13	3837
	Intra-annual	405	6937	450	5898	428	4326	419	3300	432	2955	435	4754
Battleford	Inter-annual	13	59813**	13	32279**	13	39349**	13	40063**	13	21607**	13	26510**
	Intra-annual	406	12416	420	14292	405	10930	420	8625	414	6967	396	8650
Qu'Appelle	Inter-annual	13	20313**	13	26331**	13	29875**	13	18146**	13	17577**	13	13294*
	Intra-annual	402	8636	420	7860	406	6482	417	4958	419	5030	405	6037

† *1923–1930.*

* *Exceeds intra-annual mean square, 5% level of significance.*

** *Exceeds intra-annual mean square, 1% level of significance.*

resultant vector for each month, deduced from the westerly and northerly components, is represented individually. The annual fluctuations in question occur to some extent in all months, but are most pronounced in the first half of the season, April to June.

Daily Mileage

Two aspects of the daily mileage are of particular interest, *viz.*, the variance and frequency distribution characteristic of each month.

Table IV shows the results of an analysis of the total variance of the daily observations for April, May, – – – – September, at each station into components within and between years. On the whole, the mean squares between years tend to exceed those within years, suggesting that the average wind velocity of *e.g.*, July in an individual year is to some extent affected by sources of variation other than those resulting in the day-to-day differences within months. Whilst this is brought out most clearly in the records for Battleford and Qu'Appelle, which are more extensive than those available for Lacombe and more homogeneous than those for Calgary, significant inter-annual variation was demonstrable in the previously examined records of both precipitation and temperature at the Alberta as well as at the Saskatchewan stations (1, 2).

TABLE V

INTRA-MONTHLY STANDARD DEVIATION OF DAILY WIND MILEAGE, 1922–1937

Station	Standard deviation	April	May	June	July	August	Sept.
Lacombe†	Miles per day	75	82	81	60	49	68
	As % of mean	38	39	42	36	34	40
Calgary	Miles per day	83	77	66	57	54	69
	As % of mean	43	39	36	36	33	40
Battleford	Miles per day	111	120	104	93	83	93
	As % of mean	47	48	48	46	45	47
Qu'Appelle	Miles per day	93	89	80	70	71	78
	As % of mean	38	37	37	36	36	36

† *1923–1930.*

Table V shows the intra-monthly standard deviations of daily wind mileage, computed from the intra-annual mean squares of Table IV and indicative of the day-to-day variation experienced within each of the six months. These are given in terms of actual mileage per day and also as a percentage of the mean, often termed the "coefficient of variation". At all four stations the variation in actual mileage per day is greatest in spring (April and May), diminishes progressively throughout the summer, and begins to increase again in September. The mean mileage recorded shows a similar seasonal trend (Table I), with the result that the percentage intra-monthly variation at

Battleford and Qu'Appelle is practically the same for all six months considered. At Lacombe and Calgary, on the other hand, the summer decrease in day-to-day variability is rather more than proportional to the diminution in mean mileage. In all cases the general level of variation indicated is quite high, the standard deviations, comprising roughly one-quarter of the main range, being themselves of the order of 40%, and approaching 50% at Battleford.

Tables VI to IX summarize by months the frequency distribution of the daily mileages recorded at the four stations. The first column of each of these tables indicates the class intervals into which the observations have been grouped, and the second column the average m.p.h. corresponding to the preceding daily totals. This latter figure is useful as a mental reference point, but must, however, be regarded as to some extent conventional, as the average diurnal distribution of wind between the night- and day-time hours is unequal. The main body of each table is then divided into two portions, the first showing for each of the six months separately the percentage frequency of daily totals of the various mileage classes, and the second the percentage (to the nearest unit) of days on which successive values were exceeded.

In all cases the frequency of occurrence of the different daily totals follows a well-defined pattern. Daily mileages of the lowest order, 0 to 60 m.p.d., are rare, but thereafter the number of occurrences in the successive classes rises rapidly to a maximum, from which it diminishes somewhat more gradually as the higher values are traversed. All the frequency distributions thus generated are asymmetrical, the great majority of the observations falling in the lower half of the range of variation and the higher mileages occurring relatively infrequently. This "tail" of high values is much more pronounced in spring than in summer. Thus at Battleford, for example, (Table VIII) 29% of the daily totals recorded for May exceed 300 miles (an average of 12.5 m.p.h.), whereas the corresponding figure for August is only 12%. In this connection, it may be noted that an increase in the incidence of light winds is particularly desirable when crops must be produced under conditions of limited moisture supply, as experiments (3) indicate that the transpiration of plants tends to increase as the square root of the wind velocity, rather than in direct proportion to the velocity itself. A reduction in velocity from 7.5 to 5 m.p.h. would therefore cut down the rate of transpiration more than a reduction of from 10 to 7.5 m.p.h.

Not only the general pattern of the frequency distribution, but also its seasonal trend, is similar at all four stations. However, some of the differences in detail shown in Tables VI to IX may be of considerable practical importance. At Lacombe, central Alberta, for example, only 10% of the August days for which records are available exceed 10 m.p.h. in average wind velocity (Table VI), whereas this value is exceeded in 28% of cases at Qu'Appelle, southern Saskatchewan (Table IX).

Diurnal Variation

Diurnal variation in the incidence of winds was studied by an examination of hourly mileage records. Owing to the labour involved in dealing with the

TABLE VI

FREQUENCY DISTRIBUTION OF DAILY WIND MILEAGE, LACOMBE, 1923–1930

Daily mileage	Average m.p.h.	Percentage frequency of occurrence						Percentage frequency with which exceeded					
		April	May	June	July	August	Sept.	April	May	June	July	August	Sept.
0– 60	0– 2.5	0.4	0.0	0.0	0.0	0.8	1.3	>99	100	100	100	>99	99
60–120	2.5– 5.0	11.0	7.9	12.5	25.4	36.3	26.5	89	92	88	75	63	72
120–180	5.0– 7.5	34.6	32.1	40.6	38.9	41.3	34.8	54	60	47	36	22	37
180–240	7.5–10.0	29.3	30.8	24.4	23.8	16.7	21.7	25	29	22	12	5	16
240–300	10.0–12.5	13.7	17.5	14.4	9.0	3.2	10.4	11	12	8	3	2	5
300–360	12.5–15.0	8.4	7.3	4.2	1.6	1.6	2.9	3	4	4	1	—	2
360–420	15.0–17.5	0.9	1.6	1.9	0.8	0.0	2.1	2	3	2	<1	—	<1
420–480	17.5–20.0	1.3	1.2	0.8	0.4	0.0	0.4	<1	2	1	—	—	—
480–540	20.0–22.5	0.4	0.8	0.4	0.0	0.0	0.0	—	<1	<1	—	—	—
540–600	22.5–25.0	0.0	0.8	0.4	0.0	0.0	0.0	—	—	<1	—	—	—
600–660	25.0–27.5	0.0	0.0	0.4	0.0	0.0	0.0	—	—	—	—	—	—

TABLE VII

FREQUENCY DISTRIBUTION OF DAILY WIND MILEAGE, CALGARY, 1923–1937

Daily mileage	Average m.p.h.	Percentage frequency of occurrence						Percentage frequency with which exceeded					
		April	May	June	July	August	Sept.	April	May	June	July	August	Sept.
0– 60	0– 2.5	1.4	0.4	0.4	2.8	0.7	1.2	99	>99	>99	97	>99	99
60–120	2.5– 5.0	14.4	14.5	14.2	25.4	27.9	25.6	84	85	85	72	71	73
120–180	5.0– 7.5	31.3	33.5	38.5	37.4	38.1	35.6	53	52	47	34	33	38
180–240	7.5–10.0	28.5	25.7	25.2	21.6	19.2	23.1	24	26	22	13	14	14
240–300	10.0–12.5	13.6	14.8	13.8	8.4	8.9	8.0	11	11	8	4	5	6
300–360	12.5–15.0	5.7	6.5	4.1	3.5	4.3	4.1	5	5	4	1	1	2
360–420	15.0–17.5	2.6	2.2	3.4	0.5	0.7	1.8	2	2	<1	<1	<1	<1
420–480	17.5–20.0	1.0	0.9	0.0	0.0	0.2	0.2	2	2	<1	<1	—	<1
480–540	20.0–22.5	0.5	0.9	0.0	0.0	0.0	0.0	1	1	<1	<1	—	<1
540–600	22.5–25.0	0.2	0.2	0.4	0.5	0.0	0.2	<1	<1	—	—	—	<1
600–660	25.0–27.5	0.2	0.0	0.0	0.0	0.0	0.0	<1	<1	—	—	—	<1
660–720	27.5–30.0	0.2	0.4	0.0	0.0	0.0	0.2	<1	—	—	—	—	—
720–780	30.0–32.5	0.0	0.0	0.0	0.0	0.0	0.0	<1	—	—	—	—	—
780–	32.5–	0.2	0.0	0.0	0.0	0.0	0.0	—	—	—	—	—	—

TABLE VIII

FREQUENCY DISTRIBUTION OF DAILY WIND MILEAGE, BATTLEFORD, 1924–1937

Daily mileage	Average m.p.h.	Percentage frequency of occurrence						Percentage frequency with which exceeded					
		April	May	June	July	August	Sept.	April	May	June	July	August	Sept.
0– 60	0– 2.5	2.9	1.2	1.9	1.6	1.9	1.0	97	99	98	98	98	99
60–120	2.5– 5.0	12.9	10.3	18.4	16.9	23.5	17.0	84	88	80	81	75	82
120–180	5.0– 7.5	19.3	21.8	23.9	30.3	30.1	34.8	65	67	56	51	44	47
180–240	7.5–10.0	21.5	21.1	21.5	20.5	21.6	20.5	43	46	34	31	23	27
240–300	10.0–12.5	17.6	16.9	13.5	13.9	10.5	12.2	26	29	21	17	12	14
300–360	12.5–15.0	12.5	10.5	11.3	9.3	8.1	7.7	13	18	10	7	4	7
360–420	15.0–17.5	5.8	8.9	4.1	4.6	3.6	3.9	7	9	5	3	1	3
420–480	17.5–20.0	3.5	4.1	3.1	1.4	0.5	1.3	4	5	2	1	<1	2
480–540	20.0–22.5	1.9	2.5	0.7	0.5	0.2	1.0	2	3	2	<1	<1	1
540–600	22.5–25.0	1.0	1.6	1.1	0.7	0.0	0.2	1	1	<1	<1	—	<1
600–660	25.0–27.5	1.0	0.9	0.6	0.2	0.0	0.5	<1	<1	<1	<1	—	<1
660–	27.5–	0.2	0.2	0.0	0.0	0.0	0.0	—	—	—	—	—	—

TABLE IX

FREQUENCY DISTRIBUTION OF DAILY WIND MILEAGE, QU'APPELLE, 1922–1937

Daily mileage	Average m.p.h.	Percentage frequency of occurrence						Percentage frequency with which exceeded					
		April	May	June	July	August	Sept.	April	May	June	July	August	Sept.
0– 60	0– 2.5	0.2	0.9	0.5	0.0	0.2	0.2	>99	>99	>99	100	>99	>99
60–120	2.5– 5.0	7.3	6.0	9.5	12.5	12.5	10.3	92	93	90	88	87	90
120–180	5.0– 7.5	20.3	23.4	27.4	38.6	34.2	25.3	72	70	63	49	53	64
180–240	7.5–10.0	25.0	22.0	31.9	26.3	24.7	30.7	47	48	31	26	28	34
240–300	10.0–12.5	21.2	23.8	17.3	13.5	21.0	20.8	26	24	13	9	7	13
300–360	12.5–15.0	13.3	12.9	6.9	6.8	5.0	7.5	13	11	6	2	2	5
360–420	15.0–17.5	7.7	6.6	3.7	0.8	1.0	3.6	5	4	3	1	1	2
420–480	17.5–20.0	3.7	3.5	1.9	1.2	1.2	1.2	1	1	1	<1	<1	<1
480–540	20.0–22.5	0.7	0.7	0.5	0.0	0.0	0.2	<1	<1	<1	<1	<1	<1
540–600	22.5–25.0	0.2	0.0	0.5	0.2	0.2	0.2	<1	<1	<1	—	—	—
600–660	25.0–27.5	0.2	0.2	0.0	0.0	0.0	0.0	—	—	—	—	—	—

number of individual observations concerned, two stations only were selected for this purpose, *viz.*, Lacombe (central Alberta) and Qu'Appelle (southern Saskatchewan).

Table X shows for each month separately the average for the four years 1924, 1928, 1932 and 1936 of the mileage recorded during successive hours of the day at Qu'Appelle. The hourly averages for all six months show a definite diurnal trend, increasing during the forenoon and early afternoon until a maximum is attained in the vicinity of 3 p.m., then falling off markedly until about 10 p.m., after which there is little substantial change until some time subsequent to sunrise the next morning. In these respects the average

TABLE X

DIURNAL TREND OF AVERAGE WIND MILEAGE AT QU'APPELLE, SASKATCHEWAN, COMPUTED FROM HOURLY RECORDS FOR 1924, 1928, 1932, AND 1936

Hourly interval	Average mileage recorded					
	April	May	June	July	August	September
12–1 a.m.	8.1	7.1	6.1	6.5	6.8	7.5
1–2	8.0	7.0	6.3	6.7	6.8	7.4
2–3	8.1	7.1	6.5	6.5	6.7	7.5
3–4	8.1	7.2	6.3	6.4	6.9	7.6
4–5	8.0	7.4	6.5	6.5	7.0	7.8
5–6	7.9	7.3	6.6	6.5	6.9	7.9
6–7	8.6	7.7	7.2	6.6	7.1	7.9
7–8	9.1	8.3	7.6	7.0	7.2	8.1
8–9	9.9	9.7	8.3	7.8	8.0	8.7
9–10	10.5	10.6	9.0	8.5	8.7	9.3
10–11	11.2	11.5	9.7	8.9	9.3	9.9
11–12	11.3	11.8	9.6	9.3	9.9	10.2
12–1 p.m.	11.3	11.9	9.9	9.6	10.3	10.7
1–2	11.8	11.9	10.1	9.8	10.5	10.9
2–3	11.7	12.1	10.1	9.9	10.5	11.2
3–4	11.4	12.3	9.7	9.7	10.3	11.2
4–5	10.7	11.7	9.4	9.6	9.4	10.7
5–6	10.0	11.3	9.0	9.1	8.7	9.3
6–7	9.2	10.4	8.0	8.4	7.6	8.1
7–8	8.6	9.1	7.4	7.4	6.9	7.5
8–9	7.8	7.8	6.6	6.8	6.1	6.9
9–10	7.5	6.9	6.1	6.4	6.0	7.0
10–11	7.6	6.8	6.0	6.3	6.3	7.1
11–12	7.6	6.7	6.1	6.9	6.5	7.4

TABLE XI

PROPORTION OF AVERAGE WIND MILEAGE AT QU'APPELLE, SASKATCHEWAN, FOR 1924, 1928, 1932 AND 1936, RECORDED IN DIFFERENT QUARTERS OF THE DAY

Interval	April	May	June	July	August	September
12–6 a.m.	21.6%	19.4%	20.4%	20.9%	21.6%	22.0%
6–12 a.m.	27.0	26.9	27.3	25.7	26.4	26.0
12–6 p.m.	29.8	32.1	30.9	30.8	31.3	30.8
6–12 p.m.	21.6	21.6	21.4	22.6	20.7	21.2

diurnal march of wind mileage is very similar to that of air temperature (2), but whereas the amplitude of the diurnal variation in air temperature is greater in summer than in spring, the reverse situation obtains in the case of wind mileage.

It follows from the diurnal trend indicated that on the average a greater mileage of wind is recorded during the daytime than at night. The extent of this inequality is illustrated in Table XI, which shows the proportion of the average daily total mileage recorded in different quarters of the day. This is a feature of some practical significance, as shown by the experiments of Martin and Clements (3), which indicated that the effect of wind in accelerating the transpiration of sunflowers was about 20 times greater during the day, when the leaf stomata were open, than at night, when they were closed. It may also be noted that the third quarter of the day, having the highest average wind mileage, is also on the average the period of maximum temperature and minimum relative humidity.

Although, as was mentioned previously, the actual amplitude of the diurnal variation in average wind mileage is somewhat greater in spring than in summer, the percentage variation is much the same for all six months.

Tables XII and XIII, which are similar in form to Tables X and XI, show the averages obtained for Lacombe. These are computed from only two years'

TABLE XII

DIURNAL TREND OF AVERAGE WIND MILEAGE AT LACOMBE, ALBERTA, COMPUTED FROM HOURLY RECORDS FOR 1924 AND 1928

Hourly interval	Average mileage recorded					
	April	May	June	July	August	September
12–1 a.m.	5.4	6.0	5.1	5.4	4.4	5.4
1–2	5.3	6.5	5.5	5.4	4.5	5.5
2–3	5.0	5.6	5.0	5.3	4.5	5.5
3–4	5.2	5.4	5.0	5.3	4.4	5.8
4–5	5.6	6.2	5.1	5.7	4.9	6.1
5–6	5.9	6.4	5.4	6.1	4.6	5.7
6–7	6.1	7.4	6.6	6.2	4.3	5.5
7–8	6.9	9.3	7.5	7.4	5.5	6.4
8–9	7.5	9.2	8.0	8.0	5.6	7.6
9–10	8.8	10.7	9.0	8.4	6.5	8.4
10–11	10.1	11.3	9.6	8.7	7.9	9.6
11–12	9.6	11.4	10.0	9.2	7.9	10.0
12–1 p.m.	9.9	11.6	10.3	9.2	8.0	9.6
1–2	9.7	11.5	10.0	9.5	8.2	9.6
2–3	9.0	10.4	9.5	8.9	8.4	9.5
3–4	9.2	11.3	9.6	8.7	8.1	10.0
4–5	9.1	11.4	9.4	8.8	8.1	9.4
5–6	8.6	11.0	9.6	8.7	6.8	7.7
6–7	7.4	9.3	8.5	7.7	5.6	6.2
7–8	6.7	7.4	6.8	6.9	5.2	5.8
8–9	6.0	6.0	6.1	6.4	4.4	5.4
9–10	6.0	6.4	5.6	6.4	4.5	5.8
10–11	6.4	6.6	5.8	5.7	4.5	5.7
11–12	5.7	6.1	5.7	5.9	4.4	5.4

records, 1924 and 1928, owing to the subsequently defective condition of the anemometer. For this reason, the hourly means are somewhat more irregular than those for Qu'Appelle, but the general trend is substantially the same.

TABLE XIII

PROPORTION OF AVERAGE WIND MILEAGE AT LACOMBE, ALBERTA, FOR 1924 AND 1928, RECORDED IN DIFFERENT QUARTERS OF THE DAY

Interval	April	May	June	July	August	September
12–6 a.m.	18.5%	17.7%	17.4%	19.1%	19.3%	19.8%
6–12	28.0	29.0	28.4	27.5	26.7	27.7
12–6 p.m.	31.7	32.9	32.7	30.9	33.7	32.5
6–12	21.8	20.4	21.5	22.5	20.3	20.0

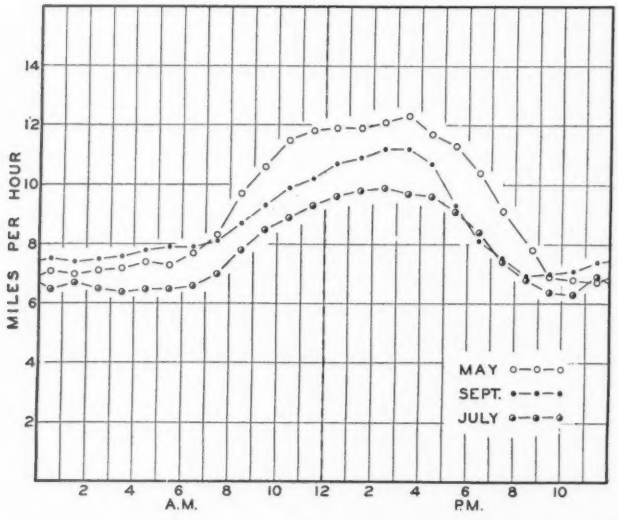

FIG. 3. *Average diurnal wind mileage curves for May, July and September at Qu'Appelle, Saskatchewan, computed from hourly records for 1294, 1928, 1932 and 1936.*

The foregoing remarks apply, of course, to the average values of Tables X to XIII, which are in each case the mean of 120 to 124 daily observations at Qu'Appelle or 60 to 62 at Lacombe. It would, however, be erroneous to suppose that the average trends indicated are closely or even approximately reproduced on the majority of individual days. In practice, the incidence of winds at any specified point is considerably affected by the passage of the successive high and low pressure systems which are such a characteristic feature of the climate of temperate regions, as well as by more local convectional effects, and these may operate to modify or to mask completely

the underlying trends noted above. This will be appreciated from a comparison of Fig. 3, which illustrates the diurnal course of the averages of Table X for the three months, May, July and September, with Fig. 4, which shows the actual sequence of hourly values recorded during the first 28 days of July, 1932. The contrast between Figs. 3 and 4 incidentally provides a good example of the somewhat abstract character of many so-called meteorological "normals".

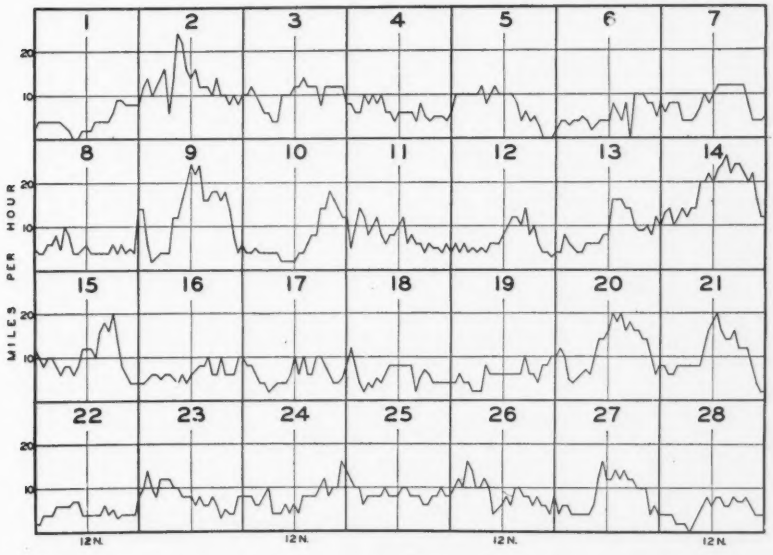

FIG. 4. *Hourly mileage of wind recorded at Qu'Appelle, Saskatchewan, during the first 28 days of July, 1932.*

Hourly Mileage

The individual values used in the computation of the foregoing diurnal trends also provide material for the study of the hourly frequency distributions characteristic of each month. Tables XIV and XV accordingly show the average percentage frequency of occurrence of different hourly mileages during the four and two representative years at Qu'Appelle and Lacombe respectively.

As in the case of the daily totals classified in Tables VI–IX, the frequency distribution of the hourly mileages follows a well-defined pattern. Very low values are again infrequent, and the majority of the observations once more fall in the lower half of the range of variation, being exceeded by a "tail" of higher mileages which diminishes progressively from April–May to August. The resulting skewness of the distributions is, however, less marked than in the case of the daily totals, being accentuated in the latter by the tendency

TABLE XIV

FREQUENCY DISTRIBUTION OF HOURLY WIND MILEAGE, QU'APPELLE, 1924, 1928, 1932 AND 1936

Hourly mileage	Percentage frequency of occurrence						Percentage frequency with which exceeded					
	April	May	June	July	August	Sept.	April	May	June	July	August	Sept.
0– 1.5	2.8	3.2	3.6	1.7	1.2	0.9	97	97	96	98	99	99
1.5– 3.5	8.1	8.0	10.2	9.4	9.8	6.5	89	89	86	89	89	93
3.5– 5.5	15.4	14.5	20.5	20.7	22.6	18.3	74	74	66	68	66	74
5.5– 7.5	15.5	15.9	18.2	20.4	20.6	20.4	58	58	48	48	46	54
7.5– 9.5	13.0	14.3	15.5	16.0	15.2	17.4	45	44	32	32	31	36
9.5–11.5	12.0	12.5	12.1	12.1	11.5	12.1	33	32	20	20	19	25
11.5–13.5	11.0	10.3	8.2	9.3	6.2	9.0	22	21	12	10	13	16
13.5–15.5	7.6	7.8	4.8	5.2	5.0	6.4	15	14	7	5	8	9
15.5–17.5	5.8	5.0	2.9	2.7	3.5	3.8	9	8	4	2	4	6
17.5–19.5	3.7	3.6	1.4	1.1	2.0	2.1	5	5	3	1	2	4
19.5–21.5	2.8	2.2	1.5	0.5	1.4	1.4	2	3	1	<1	1	2
21.5–23.5	1.2	1.4	0.7	0.4	0.3	0.7	1	1	<1	<1	<1	1
23.5–25.5	0.7	0.6	0.3	0.2	0.2	0.4	<1	<1	<1	<1	<1	1
25.5–27.5	0.2	0.4	0.0	0.1	0.3	0.3	<1	<1	<1	<1	<1	<1
27.5–29.5	0.2	0.2	0.1	0.1	0.2	0.2	—	<1	<1	—	<1	—
29.5–31.5	0.0	0.1	0.1	0.0	0.1	0.0	—	—	—	—	<1	—
31.5–33.5	0.0	0.0	0.0	0.0	0.1	0.0	—	—	—	—	—	—

TABLE XV

FREQUENCY DISTRIBUTION OF HOURLY WIND MILEAGE, LACOMBE, 1924 AND 1928

Hourly mileage	Percentage frequency of occurrence						Percentage frequency with which exceeded					
	April	May	June	July	August	Sept.	April	May	June	July	August	Sept.
0– 1.5	6.4	4.6	4.8	4.7	8.2	5.6	94	95	95	95	92	94
1.5– 3.5	14.8	12.7	14.7	14.2	21.6	16.2	79	83	80	81	70	78
3.5– 5.5	18.6	18.2	20.6	24.2	28.0	21.7	60	64	60	57	42	56
5.5– 7.5	17.8	16.7	17.5	21.4	15.8	22.2	42	48	42	36	26	34
7.5– 9.5	14.6	12.7	13.2	11.4	11.6	10.8	28	35	29	24	15	24
9.5–11.5	11.4	9.8	11.1	8.6	5.6	7.0	16	25	18	16	9	16
11.5–13.5	6.2	7.5	6.9	5.6	3.7	4.2	10	18	11	10	6	12
13.5–15.5	4.0	6.8	5.7	3.4	1.8	4.0	6	11	6	6	4	8
15.5–17.5	2.6	3.6	2.8	2.0	1.5	3.4	4	7	3	4	2	5
17.5–19.5	1.4	2.4	1.2	1.0	0.6	2.2	2	5	2	4	2	3
19.5–21.5	1.0	1.7	0.8	1.2	0.4	1.4	1	3	<1	2	1	1
21.5–23.5	0.6	0.4	0.2	0.8	0.6	0.6	<1	3	<1	2	<1	<1
23.5–25.5	0.2	0.8	0.2	0.7	0.2	0.4	<1	2	<1	1	<1	<1
25.5–27.5	0.1	0.7	<0.1	0.4	0.2	0.0	<1	1	<1	<1	<1	<1
27.5–29.5	0.1	0.2	<0.1	0.2	0.2	0.1	—	1	—	<1	<1	<1
29.5–31.5	0.0	0.4	0.0	0.1	0.0	0.0	—	<1	—	<1	<1	<1
31.5–33.5	0.0	0.3	0.0	0.1	0.0	0.1	—	<1	—	—	<1	—
33.5–35.5	0.0	0.2	0.0	0.0	0.0	0.0	—	—	—	—	<1	—
35.5–37.5	0.0	0.0	0.0	0.0	<0.1	0.0	—	—	—	—	—	—

of high velocities to persist over a number of successive hours of the same day (*cf.* Fig. 4). This tendency is most noticeable during the summer months, and hence affects the seasonal trend also, so that this is less pronounced in the hourly than in the daily mileages, although still quite noticeable.

Figs. 5 and 6 show by means of histograms both the average frequency distributions of Tables XIV and XV and also those for each year separately, the four- and two-year averages for Qu'Appelle and Lacombe respectively

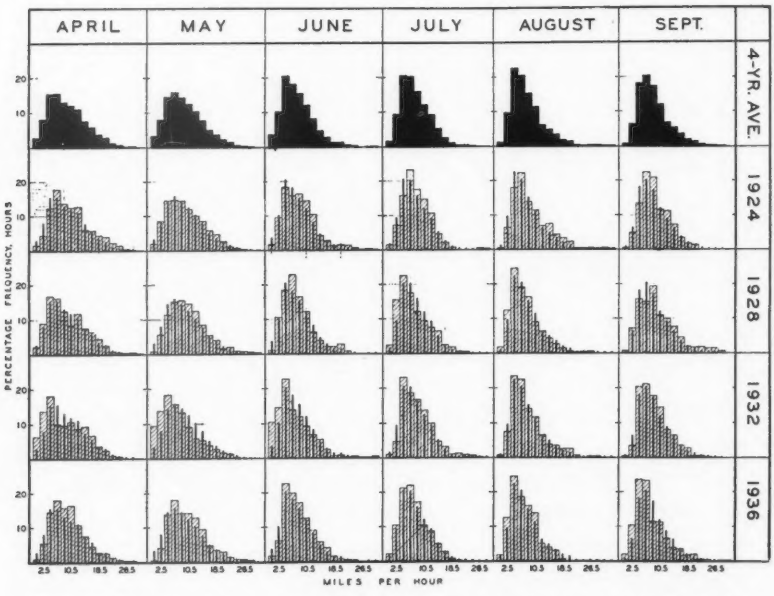

FIG. 5. *Percentage frequency distribution of hourly wind mileage at Qu'Appelle, Saskatchewan. Four-year average superimposed upon individual histograms by vertical bars.*

being superimposed on the individual histograms in the form of vertical bars to facilitate comparison. The general nature of the distribution is maintained from year to year, but there may be an appreciable fluctuation in the percentage of hours with specified mileages, particularly at the lower end of the range which, as has previously been suggested, is probably the region of most importance in its effect on evaporation and transpiration. As in the case of the daily mileages, the average proportion of lower values is significantly greater at Lacombe than at Qu'Appelle.

Relation between Daily Temperature and Wind Mileage

The final point to be considered was the nature of the association, if any, between daily temperature and wind mileage. Even a moderate degree of correlation between these two weather elements during the summer months

would, of course, be a decidedly adverse feature from the agricultural point of view. On the other hand, if they fluctuate independently, this circumstance must be taken into account. In order to study this point, daily mean temperatures at Qu'Appelle for the months of April, June and September were computed from the daily maxima and minima, and are shown plotted against the corresponding daily wind mileages in Fig. 7.

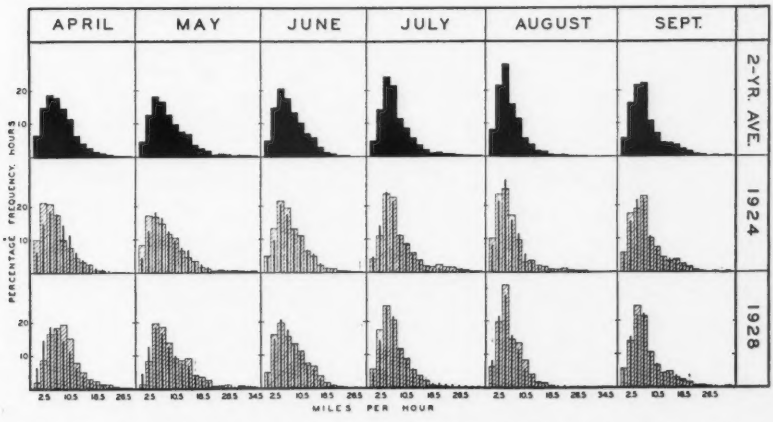

FIG. 6. *Percentage frequency distribution of hourly wind mileage at Lacombe, Alberta. Two-year average superimposed upon individual histograms by vertical bars.*

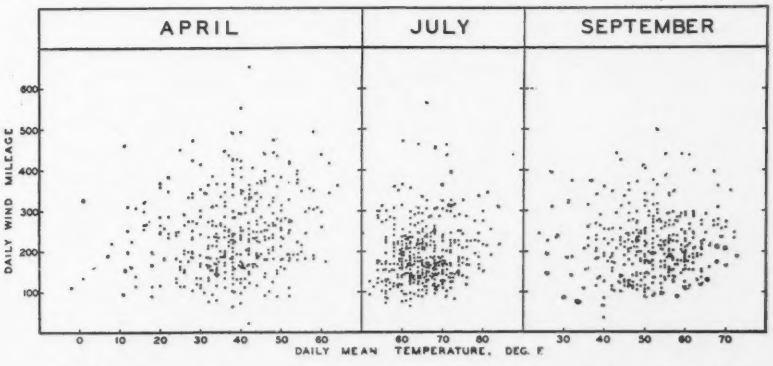

FIG. 7. *Daily temperature and wind mileage at Qu'Appelle, Saskatchewan, 1922–1937.*

The intra-monthly association of these two quantities yielded simple correlation coefficients of 0.147 for April, 0.141 for July and 0.014 for September. These are all small, but before concluding that there is little correlation between daily temperature and wind mileage, it is necessary to take

account of the fact that their average seasonal trend is dissimilar, monthly mean temperature being at its maximum in midsummer, when monthly wind mileage is at its minimum. This circumstance might operate to mask an actual positive intra-monthly correlation, but apparently did not in fact do so to any appreciable extent, as the correlation was not effectively altered by the elimination of the linear intra-monthly secular trend, the partial coefficients being 0.144, 0.141, and 0.058 for the three months respectively. As these are computed from between 300 and 400 daily values in each case, the first two, although small, are statistically significant, exceeding the 1% point. It may be surmised, therefore, that there is a slight tendency for days of above-average temperature to have a higher wind mileage, but that this is a minor factor in comparison with the uncorrelated variation of both quantities.

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VARIETAL DIFFERENCES IN BARLEYS AND MALTS

V. WORT NITROGEN AND MALT EXTRACT AND THEIR CORRELATIONS WITH BARLEY NITROGEN FRACTIONS[1]

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Abstract

Data representing 12 barley varieties grown at 12 experimental stations in Canada were used to examine relations among wort nitrogen (w), malt extract (e), barley nitrogen fractions (x), and total barley nitrogen (n).

Significant *inter-varietal* partial correlations, independent of total nitrogen, were found between wort nitrogen and salt-soluble nitrogen ($r_{wx.n} = 0.88$), and between extract and salt-soluble and insoluble nitrogen fractions ($r_{ex.n} = 0.60$ and -0.65). Partial correlations between wort nitrogen and alcohol-soluble and insoluble nitrogen were negative but insignificant ($r_{wx.n} = -0.54$ and -0.32).

Intra-varietal simple correlations between wort nitrogen and insoluble, alcohol-soluble, and salt-soluble nitrogen fractions were all positive and significant ($r_{wx} = 0.77$, 0.74, and 0.61), and those between extract and each fraction were all negative and significant ($r_{ex} = -0.88$, -0.96 and -0.77). All of the corresponding partial correlation coefficients were insignificant.

The differences between the inter- and intra-varietal relations can be summed up as follows: between varieties, total nitrogen and factors associated with it have little influence on wort nitrogen or extract, whereas nitrogen distribution and factors associated with it have a measurable effect; within varieties, total nitrogen and factors associated with it are largely responsible for the control of wort nitrogen and extract, and one of these factors is nitrogen distribution. The differences result mainly from the fact that whereas within varieties nitrogen distribution is closely related to total nitrogen content, between varieties nitrogen distribution is independent of total nitrogen content.

The relations between extract yield of malt and various barley properties have been investigated by Bishop (4–7). He made statistical studies of the relations of extract with total nitrogen, insoluble carbohydrates, 1000-kernel weight and percentage germination of the barley, and with wort nitrogen, and used these properties in developing prediction equations for malt extract. So far as the present authors are aware, no statistical study has been made of the relations between malt extract and barley nitrogen fractions, or of those between wort nitrogen and barley nitrogen fractions. It appeared that an investigation of these relations might yield useful information and it was accordingly undertaken.

Data and Methods

The experimental data were collected by analysis of 144 samples of barley and of the malts made from them. The samples represent 12 varieties grown at 12 widely separated experimental stations in Canada. A detailed description of the varieties and of the methods used in growing the samples was

[1] *Manuscript received December 31, 1938.*
Contribution from the Division of Biology and Agriculture, National Research Laboratories, Ottawa, and the Department of Plant Science, University of Manitoba, Winnipeg. Published as Paper No. 156 of the Associate Committee on Grain Research of the National Research Council and the Dominion Department of Agriculture.

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published in Part I of this series (1), which also contains summaries of the data on the total nitrogen and nitrogen fractions of the barley samples. A description of the methods used for making and analyzing the malts, and summaries of the data on extract yield and wort nitrogen, were published in Part IV (9).

The relations between each pair of properties were examined by calculating (i) the simple correlation coefficient, and the partial correlation coefficient, independent of total nitrogen, for varietal means over all stations, which represent the average inter-varietal relation; and (ii) the simple and partial correlation coefficients for station means over all varieties, which represent the average intra-varietal relation. Some multiple correlation coefficients and regression equations were also calculated when it seemed probable that these statistics would prove illuminating.

Relations between Wort Nitrogen and Barley Nitrogen Fractions

Correlation coefficients showing the relations between wort nitrogen and barley nitrogen fractions, and wort nitrogen and total barley nitrogen are given in Table I. The independent variables are listed in the first column, and the relation between wort nitrogen and each of these is represented by a row of four correlation coefficients, namely, the simple and partial correlation coefficients for varieties and stations.

TABLE I

RELATIONS AMONG WORT NITROGEN (w), BARLEY NITROGEN FRACTIONS (x), AND TOTAL BARLEY NITROGEN (n)

x = independent variables listed below	Correlation coefficients			
	Varieties		Stations	
	Simple, r_{wx}	Partial, $r_{wx.n}$	Simple, r_{wx}	Partial, $r_{wx.n}$
Insoluble protein nitrogen	−.231	−.319	.769**	.253
Alcohol-soluble protein nitrogen	−.175	−.537	.736**	−.150
Total salt-soluble nitrogen	.887**	.885**	.610*	.118
Salt-soluble protein nitrogen	.827**	.824**	.564	.005
Non-protein nitrogen	.863**	.841**	.522	−.289
Total nitrogen	.166	—	.764**	—
Residual degrees of freedom	10	9	10	9

NOTE: *In this and later tables, ** denotes that the 1% level, and * that the 5% level of significance is attained.*

Inter-varietal Relations

The inter-varietal relations between wort nitrogen and the barley nitrogen fractions are represented by the simple and partial correlation coefficients given in the first two columns of data. In considering the latter it is useful to think of them as coefficients of correlation between wort nitrogen and the property in question, after both have been adjusted for varietal differences

in total nitrogen content, *i.e.*, after the complicating influence of varietal differences in total nitrogen content has been removed. Comparison of the partial and simple correlation coefficients shows that, with respect to the inter-varietal relations, this complicating influence is relatively small. It will be wise, nevertheless, to confine further discussion to the partial correlation coefficients.

These statistics show that between varieties wort nitrogen is directly correlated with total salt-soluble nitrogen and with the two fractions into which this was split, namely, salt-soluble protein nitrogen and non-protein nitrogen. A relation of this sort might well be expected on common-sense grounds. The wort is a dilute salt solution and should contain a very considerable proportion of the salt-soluble nitrogen compounds even if these were not hydrolyzed by proteolytic enzymes during the malting and mashing processes. Moreover, the least soluble portions of the salt-soluble fraction would presumably require only mild hydrolysis to bring them into solution in the wort. We might thus expect the salt-soluble nitrogen fraction of the barley to make a fairly large direct contribution to wort nitrogen, which would be enhanced by enzymatic hydrolysis of the least soluble compounds during malting, and offset in part by a comparatively small loss of soluble nitrogen transferred to the roots and synthesized to less soluble proteins in the acrospire.

In the authors' opinion the partial correlation coefficients are surprisingly high since other factors, specifically the activity of the proteases, must play a part in controlling wort nitrogen. In this connection it is interesting to note that it was shown in Part III of this series (2) that an inter-varietal correlation exists between total salt-soluble nitrogen and total saccharifying activity of the barley ($r = 0.739$). The possibility of a corresponding correlation between salt-soluble nitrogen and proteolytic activity is thus suggested, and if such an association exists it might tend to raise the coefficient of correlation between this barley nitrogen fraction and wort nitrogen. Whatever the explanation may be, it seems clear that varieties having a larger proportion of their nitrogen in salt-soluble form tend to yield higher percentages of wort nitrogen.

It is also interesting to note that although the partial correlation coefficients for wort nitrogen and the two least soluble nitrogen fractions are not significant they are at least negative. This was to be expected since as the salt-soluble fraction increases the salt-insoluble fraction decreases, so that if the former is directly correlated with wort nitrogen the latter should be inversely correlated with wort nitrogen. This can be demonstrated by treating the insoluble and alcohol-soluble nitrogen as one fraction, salt-insoluble nitrogen. The coefficient of partial correlation between wort nitrogen and salt-insoluble nitrogen, independent of total nitrogen, proved to be -0.923.

Intra-varietal Relations

The intra-varietal relations between wort nitrogen and the other properties are shown by the simple and partial correlation coefficients given in the last

two columns in Table I. These present an entirely different picture from the corresponding one for the inter-varietal relations. The simple correlation coefficients for wort nitrogen and the two least soluble nitrogen fractions are positive and significant, and all the partial correlation coefficients are insignificant.

The explanation of the differences between the inter- and intra-varietal relations appears to lie in the fact that, whereas between varieties the nitrogen distribution is independent of total nitrogen, within varieties the distribution is more or less dependent upon total nitrogen. Thus Bishop (3) has shown that within varieties, as the total nitrogen increases, the amounts of each of the nitrogen fractions also increase more or less regularly, although not at the same rates (see also Part I of this series (1)). It thus follows that as salt-soluble nitrogen increases, alcohol-soluble and insoluble nitrogen increase also. Accordingly if a direct inter-varietal correlation is found between wort nitrogen and salt-soluble nitrogen, in accordance with expectations, direct correlations should also exist between wort nitrogen and each of the less soluble fractions.

In calculating the partial correlation coefficients adjustments are made, to both wort nitrogen and the fraction in question, for the effect of differences between stations with respect to total nitrogen. After these adjustments are made there remain only the variations resulting from irregularities in the generally regular increase in each fraction with increasing total nitrogen content. These remaining variations are not large in themselves, nor are they large in comparison with the experimental errors involved in determining them. In consequence little opportunity exists for demonstrating the possible existence of intra-varietal partial correlations between wort nitrogen and barley nitrogen fractions, independent of total nitrogen.

It seems clear that within varieties the main factors controlling wort nitrogen are associated with total nitrogen rather than with nitrogen distribution among the protein fractions. These factors are probably connected with proteolytic activity, which may well be correlated with total nitrogen within varieties, but not between varieties. Relations of this sort between malt saccharifying activity and total nitrogen have already been demonstrated in an earlier paper in this series (2).

Relations between Malt Extract and Barley Nitrogen Fractions

Inter-varietal Relations

Simple and partial correlation coefficients showing the inter-varietal relations between malt extract and each of the five barley nitrogen fractions, between malt extract and total nitrogen, and between malt extract and wort nitrogen, are given in the first two columns of data in Table II. Comparison of the simple and partial correlation coefficients shows that inter-varietal differences in total nitrogen have only a slight tendency to mask the real relations between extract and the various nitrogen fractions.

The partial correlation coefficients show that between varieties extract is inversely correlated with insoluble protein nitrogen and directly correlated with total salt-soluble nitrogen and salt-soluble protein nitrogen, but that significant correlations do not exist between extract and alcohol-soluble, non-protein nitrogen, or wort nitrogen.

TABLE II

RELATIONS AMONG MALT EXTRACT (e), BARLEY NITROGEN FRACTIONS AND WORT NITROGEN (x), AND TOTAL BARLEY NITROGEN (n)

x = independent variables listed below	Correlation coefficients			
	Varieties		Stations	
	Simple, r_{ex}	Partial, $r_{ex.n}$	Simple, r_{ex}	Partial, $r_{ex.n}$
Insoluble protein nitrogen	−.728**	−.648*	−.883**	.022
Alcohol-soluble protein nitrogen	−.200	.201	−.958**	−.319
Total salt-soluble nitrogen	.452	.604*	−.767**	.306
Salt-soluble protein nitrogen	.590*	.696*	−.641*	.321
Non-protein nitrogen	.138	.341	−.785**	.014
Total nitrogen	.380	—	−.957**	—
Wort nitrogen	.431	.542	−.716**	.073
Residual degrees of freedom	10	9	10	9

It seems best to deal first with the relation between extract and wort nitrogen. The partial correlation coefficient (0.542) fails to attain the value (0.602) required for the 5% level of significance. Nevertheless, the value is high enough to suggest that a significant partial correlation might be demonstrated by investigation of a larger number of varieties.

In the present investigation the maximum difference between varieties with respect to wort nitrogen calculated as protein was 2.0%, whereas the maximum difference in extract yield was 5.8% (see (9) Table I). Thus it appears that the amount of wort nitrogen a variety yields can have only a relatively small influence on the total yield of extract, and a close correlation between wort nitrogen and extract would hardly be expected.

Since the partial correlation between wort nitrogen and extract is not significant, the significant partial correlations between the salt-soluble nitrogen fractions and extract cannot be wholly explained by the direct contribution which these make to wort nitrogen. Some other factors must be involved, but these cannot be the result of proteolytic activity since this must also contribute only to wort nitrogen. The possibility that these factors represent the activity of various hydrolytic enzymes, other than proteases, suggests itself and receives some support from the previously noted fact that an inter-varietal association between saccharifying activity and total salt-soluble nitrogen has already been demonstrated (2).

Since the insoluble protein (glutelin) can contribute to extract only by means of hydrolysis by proteolytic enzymes, an inverse correlation between this

fraction and extract might be expected. However, since in the present study the maximum difference between varieties with respect to insoluble protein was less than 0.9% (see (1) Table III), whereas the maximum difference in extract was 5.8%, it again seems surprising that a significant correlation should be obtained. A possible explanation may be that varieties that contain larger amounts of insoluble protein also tend to contain larger amounts of the insoluble carbohydrates, lignin and cellulose.

TABLE III

INTER-STATION PREDICTION OF EXTRACT (E) FROM TOTAL NITROGEN (N) AND TOTAL SALT-SOLUBLE NITROGEN (S)

$$E = 84.4 - 6.3\,N + 5.1\,S$$

Station	Total nitrogen, %		Total salt-sol. N, %		Extract, %	
	Value	Multiplied by −6.3	Value	Multiplied by 5.1	Predicted	Found
Gilbert Plains	2.69	−16.95	.807	4.12	71.6	71.6
Nappan	1.54	− 9.70	.598	3.05	77.8	78.0
Difference	1.15	− 7.25	.209	1.07	− 6.2	−6.4

An alternative explanation also suggests itself. Bishop (5), in discussing intra-varietal relations between total nitrogen and extract, points out that the decrease in extract with increasing total nitrogen is considerably greater than would be expected if the decrease resulted merely from displacement of soluble carbohydrates by nitrogen compounds. He therefore suggests that the protein, in addition to replacing carbohydrates, "seals up" some of the remaining carbohydrates, thus making them less readily extractable. It seems possible that this sealing up, if it exists, may be largely a function of the glutelin protein which might thus have a greater effect on extract yield than would be expected from consideration of its quantity alone.

Whereas the partial correlation coefficient for insoluble nitrogen is negative and significant, that for the alcohol-soluble fraction (hordein) though insignificant, is positive. It accordingly seems reasonable to suppose that the alcohol-soluble fraction can have little effect in any sealing up of soluble carbohydrates which may exist. Bishop (8) has suggested that the alcohol-soluble protein and starch play similar roles in the grain, both acting as reserves. The possibility of some inter-varietal association between these two reserve compounds suggests itself as a possible explanation of the fact that the partial correlation coefficient for alcohol-soluble nitrogen and extract, though insignificant, is positive. On the whole, it appears more surprising that it is possible to demonstrate, with only 12 varieties, that significant correlations exist between extract and certain nitrogen fractions, than that significant correlations cannot be demonstrated between extract and other fractions.

Intra-varietal Relations

The intra-varietal relations between extract and barley nitrogen fractions, extract and total nitrogen, and extract and wort nitrogen, are shown by the simple and partial correlation coefficients given in the last two columns in Table II. The intra-varietal relations for extract are similar to, but the reverse of, the corresponding intra-varietal relations for wort nitrogen. All the simple correlation coefficients are significant and negative and all the partial correlation coefficients are insignificant.

The explanation of the differences between the inter- and intra-varietal relations for extract also appears to lie in the fact that, whereas between varieties the nitrogen distribution is independent of total nitrogen, within varieties the distribution is more or less dependent upon total nitrogen content. Within varieties the alcohol-soluble protein nitrogen and the insoluble protein nitrogen are closely correlated with total nitrogen content ($r = 0.985$ and 0.926, respectively) so that little opportunity exists for demonstrating partial correlations between these fractions and extract, independent of the effect of total nitrogen. It is quite clear, however, that as the total nitrogen increases, these two fractions increase also, and extract decreases.

It is also clear that within varieties, as total nitrogen increases, the amounts of the more soluble nitrogen fractions and of wort nitrogen also increase slightly (1), and it appears that these increases are associated with a decrease in extract. Further consideration will suggest, however, that in spite of the inverse associations, increasing amounts of the more soluble nitrogen fractions may add to extract yield. Thus within varieties and with an increase in total nitrogen, the loss of extract resulting from displacement or binding of potentially extractable carbohydrates may well be far greater than the possible gain in extract resulting from a comparatively small increase in the amount of salt-soluble nitrogen compounds entering the wort. Common sense suggests that this hypothesis is sound and it also receives some support from the fact that the partial correlation coefficients for the more soluble barley nitrogen fractions, though insignificant, are at least positive.

The possible quantitative aspects of this matter can be brought to light by calculating the regression equation for extract (E) on total nitrogen (N) and total salt-soluble nitrogen (S). This turns out to be:—

$$E = 84.4 - 6.3\,N + 5.1\,S.$$

Results obtained by using this equation are shown in Table III. The data for total nitrogen and total salt-soluble nitrogen are mean values over all varieties, and Nappan and Gilbert Plains are the stations at which total barley nitrogen was highest and lowest (see (1) Table I). It will be observed that an increase in total nitrogen content of 1.15% results in a predicted decrease in extract of 7.25%. On the other hand, the small increase in total salt-soluble nitrogen of 0.208% results in a predicted increase in extract of only 1.07%. The net decrease in extract is thus 6.2%.

This example must be considered as a hypothetical illustration of the possible simultaneous relation between extract, total nitrogen, and total salt-soluble nitrogen. Since the coefficient of partial correlation between extract and total salt-soluble nitrogen is not significant, the available data fail to prove that the corresponding partial regression coefficient is of the order of the calculated estimate, 5.1. It may even be negative, though this seems rather improbable.

The differences between the inter- and intra-varietal relations for extract can be summed up as follows: between varieties total nitrogen and factors associated with it have little influence on extract, whereas nitrogen distribution and factors associated with it have a measurable effect; within varieties total nitrogen and factors associated with it are largely responsible for the control of extract, and among these factors nitrogen distribution must be numbered. The differences result mainly from the fact that whereas within varieties nitrogen distribution is closely related to total nitrogen content, between varieties nitrogen distribution is independent of total nitrogen content.

Simultaneous Inter-varietal Relations among Malt Extract and the Nitrogen Fractions, Total Nitrogen, and 1000-kernel Weight of the Barley

The multiple correlation coefficients given in the last three columns of Table IV were calculated with the object of determining whether the inter-varietal prediction of extract from barley nitrogen fractions could be improved by introducing total nitrogen or 1000-kernel weight, or both, as additional independent variables. It was obviously useful to study further only the three nitrogen fractions which yielded significant partial correlations with extract, independent of total nitrogen content.

TABLE IV

SIMULTANEOUS INTER-VARIETAL RELATIONS AMONG MALT EXTRACT (e), BARLEY NITROGEN FRACTIONS (x), TOTAL BARLEY NITROGEN (n), AND 1000-KERNEL WEIGHT OF BARLEY (g)

x = independent variables listed below	Correlation coefficients			
	Simple, r_{ex}	Multiple, $R_{e.xn}$	Multiple, $R_{e.xg}$	Multiple, $R_{e.xng}$
Insoluble protein nitrogen	−.728**	.738*	.737*	—
Total salt-soluble nitrogen	.452	.676	.844**	.859*
Salt-soluble protein nitrogen	.590	.748*	.836**	.875**
Total nitrogen	.380	—	.470	—
Residual degrees of freedom	10	9	9	8

The multiple correlation coefficients for extract, a nitrogen fraction, and total nitrogen are given in the second column of data. Comparison of these with the corresponding simple correlation coefficients, given in the preceding column, shows that an appreciable improvement was obtained with respect

to total salt-soluble nitrogen and salt-soluble protein nitrogen. Statistical analyses showed, however, that these improvements could not be considered significant (see Table V).

TABLE V

ANALYSES OF INTER-VARIETAL VARIANCE OF MALT EXTRACT

Variance accounted for by	Degrees of freedom	Mean squares		
		x_1 = Insoluble protein nitrogen	x_1 = Total salt-soluble nitrogen	x_1 = Salt-soluble protein nitrogen
Effect of x_1	1	271.4*	104.6	178.1*
Added effect of total nitrogen	1	7.4	129.3	108.4
Residual	9	25.9	31.0	25.1
Effect of x_1	1	271.4*	104.6*	178.1**
Added effect of 1000-kernel weight	1	7.0	260.2**	203.7**
Residual	9	26.0	16.4	14.5
Effect of x_1	1	271.4*		
Added effect of total salt-sol. N	1	7.8	—	—
Residual	9	25.9		
Effect of x_1 and 1000-kernel weight	2		182.4*	190.9**
Added effect of total nitrogen	1	—	13.0	10.1
Residual	8		16.8	15.0

The effect of introducing 1000-kernel weight (G) was next investigated With respect to the insoluble protein fraction, the effect was negligible. On the other hand, significant improvements were obtained with respect to both other fractions (see Table V). It thus appears that some inter-varietal factor exists, which is common to the control of extract and 1000-kernel weight, but is not common to the control of extract and the salt-soluble nitrogen fractions.

As a further step the multiple correlation coefficients between extract, the nitrogen fraction, total nitrogen and 1000-kernel weight were calculated, for the salt-soluble protein nitrogen and total salt-soluble nitrogen fractions. These are not significantly higher than the corresponding multiple correlation coefficient in which total nitrogen is not included.

One other simultaneous relation also appeared to merit investigation, namely, that between extract, insoluble protein nitrogen, and total salt-soluble protein nitrogen. The multiple correlation coefficient proved to be 0.738, which is not significantly higher than the simple correlation coefficient for extract and insoluble protein nitrogen only, −0.728.

It is obvious that it will be necessary to obtain far higher multiple correlation coefficients before a useful inter-varietal prediction equation for extract can be developed. In the meantime it is apparent that in developing such an equation insoluble protein nitrogen alone, or total salt-soluble nitrogen in combination with 1000-kernel weight, may prove useful. It should be noted

that the two-stage extraction method (5% potassium sulphate followed by hot 70% alcohol), used for determining insoluble protein nitrogen, precludes its ready use for prediction purposes. There is reason to believe, however, that the determination could be made using a single solvent, possibly 8% sodium salicylate solution (10).

Analyses of Variance

In order to determine whether the multiple correlation for extract and two independent variables could be considered significantly higher than the simple correlation between extract and the first variable, the inter-varietal variance for extract was analysed into portions accounted for by: (i) the first independent variable; (ii) the added effect of the second independent variable; and (iii) the residual variance. When the mean square for the added effect of the second variable proves to be significantly greater than the residual mean square, the multiple correlation coefficient can be considered significantly greater than the corresponding simple correlation coefficient.

The resulting mean squares for seven of these analyses are given in the first three sections of Table V. It is apparent that significantly higher multiple correlations were obtained only by combining 1000-kernel weight with either total salt-soluble nitrogen or salt-soluble protein nitrogen.

The last section of Table V gives the mean squares for corresponding analyses designed to determine whether the addition of a third independent variable raised the multiple correlation coefficient significantly. The statistics show that no significant increase was obtained.

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Canadian Journal of Research

Issued by THE NATIONAL RESEARCH COUNCIL OF CANADA

VOL. 17, SEC. D. JANUARY, 1939 NUMBER 1

COLOUR OF MEAT: I. APPARATUS FOR ITS MEASUREMENT, AND RELATION BETWEEN pH AND COLOUR[1]

BY C. A. WINKLER[2]

Abstract

A photoelectric colour comparator, similar to that designed by Bolton and Williams (1), has been constructed and used to compare the colours of meat samples at different pH. Light falls at an angle of 45° on the surface of the sample, and the amount scattered at right angles from the surface in the red, green, and blue regions of the spectrum, defined by standard colour filters in the path of the scattered light, is measured photoelectrically as a percentage of the amount similarly scattered in the same spectral regions from a standard white surface under the same light intensity. The precision of the measurements on meats was $\pm 0.25\%$ scatter with any one of the three filters.

When samples of pork, beef, and mutton were used, after adjustment of the pH by injections of lactic acid or ammonia, the relation between pH and colour was found to be similar for the three meats, with maximum scatter of red, green, and blue at pH about 5.0 – 5.5. When uninjected samples of pork were used, scatter in the three spectral regions decreased over the pH range 5.4 – 6.6, paralleling the changes observed with injected samples within the same pH limits. The visual appearance of the meats is greyish at pH levels acid to the region of maximum scatter and pink in the region of maximum scatter, shading to dark red at higher pH levels. Darkening is paralleled by a decrease in the scatter, while changes in the quality of the colour are accompanied by changes in the ratio of red/green and red/blue.

Introduction

Good colour in meat, while it might not affect its palatability or nutritive value, is generally recognized and demanded by the consumer. The economic significance of colour and colour stability in meat is therefore obvious.

Of the work that has been done on the colour of meat, that of Brooks (2, 3), Mackintosh and his associates (5, 6, 7), and Heiss and Hohler (4) is probably of greatest interest to the meat packing industry. Much remains to be done, however, and studies of the factors that influence the colour and colour stability of meats, particularly pork and bacon, are being made as part of a program of researches on meats in these laboratories.

Sair and Cook (8, 9) have recently published the results of a study of "drip" from various meats. In the course of their work they observed what appeared to be a relation between pH and colour of the meats. The present paper describes a quantitative study of the relation between pH and colour for pork, beef and mutton.

[1] *Manuscript received November 16, 1938.*

Contribution from the Division of Biology and Agriculture, National Research Laboratories, Ottawa. Issued as Paper No. 15 of the Canadian Committee on Storage and Transport of Food.

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Apparatus

The colour comparator used in these investigations was similar in essential features to that described by Bolton and Williams (1) and is shown diagrammatically in Fig. 1.

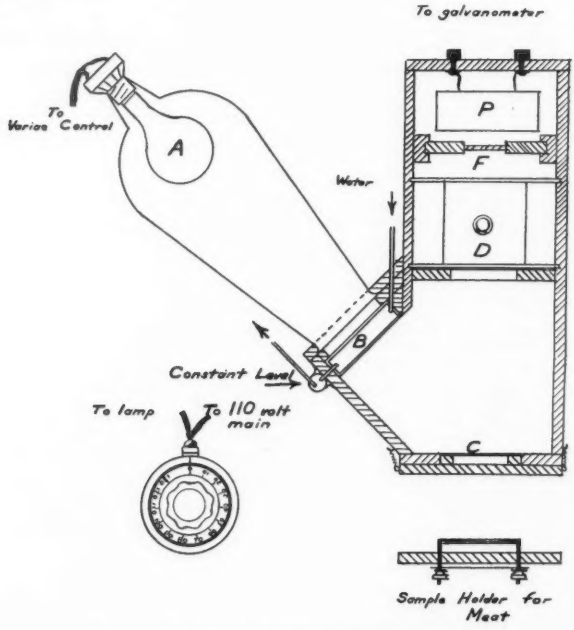

FIG. 1. *Diagram of colour comparator for meats.*

The light source *A* ("Photoflood" bulb) was mounted in front of a reflector and controlled with a "Variac" transformer. The infra-red radiation reaching the sample was reduced by the passage of the light through water in the glass cell *B*. The light fell at an angle of 45° on the surface of the sample at *C*. The light, scattered approximately at right angles to the surface of the sample, passed through another glass cell *D*, containing a dilute solution of copper sulphate, to remove any infra-red that might be present in the scattered light. Suitable glass colour filters were inserted in the path of the scattered light at *F*, and the filtered radiation was received on a "Photronic" photoelectric cell *P* connected to a sensitive galvanometer.

A magnesium carbonate block was mounted on a holder that could be put in place at *C*. A circular area of two square inches of white surface, covered with a thin glass slide, was exposed. The holder for the test sample consisted of a solid back against which the meat, between thin glass slides, was held in position by a stiff metal plate having a circular hole two square inches in area. The area of meat surface and the area of standard white surface exposed

to the light were therefore equal. Small surface irregularities in the meat sample were eliminated by compressing it slightly between the glass slides.

The method used to measure the colour characteristics of a sample of meat was similar to that described by Bolton and Williams (1). With one of the colour filters and the standard white surface in place, the intensity of the light source was adjusted to give some chosen galvanometer deflection d. The standard white surface was then replaced by the meat sample, and the galvanometer deflection d_1 obtained. For the colour filter used, the percentage scatter by the sample is then given by $100\,\frac{d_1}{d}$. The procedure was repeated for other colour filters.

In preliminary tests with the apparatus, several colour filters were used, with a view to obtaining a fairly detailed spectrophotometric analysis of the meat samples. It soon became apparent, however, that sampling errors were too large to justify a detailed colour analysis, and three filters only were finally used. The wave-length ranges over which these transmitted were: blue, 4000 – 4500 Å; green, 4900 – 5800 Å; red, 5750 – 7000 Å. Results are expressed simply as percentage scatter of blue, green and red.

Tests with the apparatus showed that different "photoflood" bulbs and different photoelectric cells gave the same values for the scatter from a given meat sample. It was also found that the time during which the meat was exposed to the intense light, in making measurements with three filters, was not long enough for the colour of the meat to change under the action of the light. With practice, it was possible to make measurements with three filters in about three minutes, and most of this time was taken up in adjusting the light intensity with the standard white surface in position.

The precision of the apparatus has been determined by successive measurements with a given sample of meat, and by measuring the colour of the surfaces along which the knife passes when two samples are prepared from a single piece of meat. By both these methods the value obtained for the percentage scatter could be checked within $\pm 0.25\%$ with any one of the three filters.

The percentage scatter from two pieces cut from the same muscle of a carcass and brought to the same pH may differ by an amount several times the limit of precision for the apparatus. The magnitude of this sampling error is illustrated in Table I.

TABLE I

VARIATION IN COLOUR, AT THE SAME pH, FOR DUPLICATE SAMPLES FROM THE SAME MUSCLE

Type of meat	pH	Light scattered, %		
		Red	Green	Blue
Pork	5.0	21.1	19.5	16.8
		26.2	23.5	18.2
Beef	5.5	30.0	14.0	14.0
		30.0	14.4	14.8
Pork	5.6	33.0	25.4	19.8
		31.8	24.7	20.0
Pork	5.8	39.5	28.2	24.3
		42.4	26.8	23.5

The values, taken at random from the results obtained with pork and beef, show at once that the precision of the method adopted for measuring the colour was adequate for the investigation.

Experimental Procedure and Results

Unminced samples (100 to 200 gm. each) from a given muscle of pork and mutton were brought to various pH levels by the method described by Sair

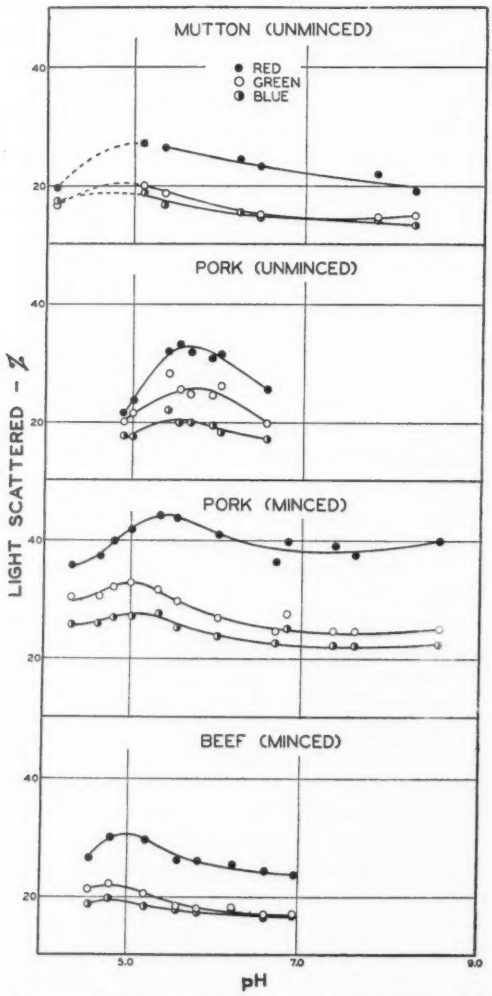

FIG. 2. *pH—Colour relation for mutton, pork and beef. Samples injected with lactic acid and ammonia to alter pH.*

and Cook (9). It consisted simply of injecting into the meat dilute lactic acid or ammonia solutions of suitable concentrations, followed by 3 to 5 days' storage of the samples at 0° C. A slice was taken from each sample after its removal from storage, and the colour measured. The pH of each slice was determined with a glass electrode. A typical curve for pork is shown in Fig. 2; only one experiment was made with mutton, the results of which are also shown in Fig. 2.

The colour, prior to injection, of the samples used in the experiments described above differed appreciably, and it is probable that the variation in initial colour was reflected, to some extent at least, in the colours developed after injection. It was thought worth while, therefore, to check the results by making experiments in which differences in initial colour were eliminated. This was done by mincing and thoroughly mixing the meat before injections were made. The batch was divided into several portions, and their similarity of colour checked with the colour comparator. They were then injected and stored, with frequent mixing. Typical results for minced pork and beef are represented in Fig. 2.

The range of pH obtainable with the injection method is much greater than that existing normally in carcasses. The pH and colour of cuts from a number of hog carcasses were therefore measured to find out if any relation between colour and pH could be detected for untreated pork. The samples were taken from carcasses in a commercial abattoir, the only factor limiting their choice being that they should be from corresponding muscles of the carcasses. Samples were taken on two different days, at least four cuts at each pH being measured. The average values for the colour at different pH levels are plotted in Fig. 3.

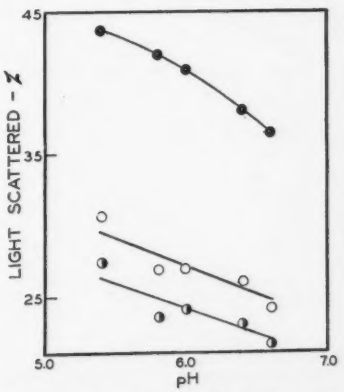

FIG. 3. *Average pH—Colour relation for pork from different carcasses. No injections of lactic acid or ammonia. Identity of curves as in Fig. 2.*

In Fig. 4 are plotted the ratios of the scatters together with the scatter of red from the minced pork. The visual appearance of the samples is also given for the pH regions in which the colour changes were sufficiently marked for recognition; above and below the pH levels at which the meat appeared pink are regions in which it was difficult to describe the colour as it shaded from pink through light brown to grey, or from pink to darker red.

Interpretation and Discussion

By examination of the curve for red scatter (Fig. 4) in conjunction with the curves for the ratios, changes in intensity and quality of the colour respectively

can be fairly well described. As a scattering surface becomes lighter in colour, the percentage scatter of all wave bands increases, while if the surface becomes darker the reverse is true. As the trends of the curves for red, green and blue scatters are similar (Fig. 3) the curve for red scatter alone is sufficient to show that from pH about 4.5 to pH about 5.5 the samples become lighter, and beyond pH 5.5, darker in colour. Fig. 4 shows also that there is an increase of approximately 25% in the ratio of red scatter to blue and green scatters

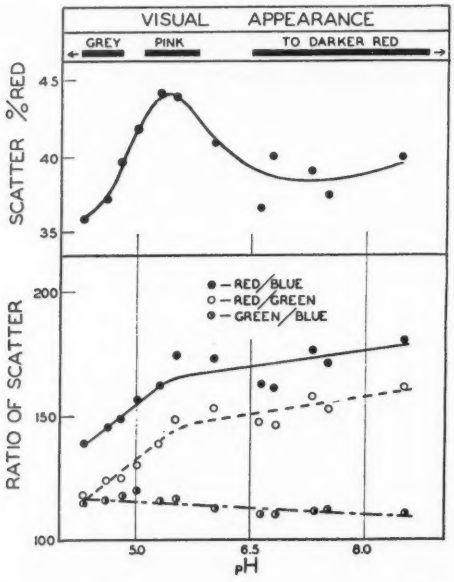

FIG. 4. *Relation between pH and ratios of scatters, red scatter and visual appearance (minced pork).*

over the pH range about 4.5 to 5.5, paralleling the visually observed change in composition of the colour from grey through light brown to the normal pink colour. From pH 5.5 to 8.5 the ratios of red/green and red/blue increase by only about 8%, and the change over this pH range is mainly in intensity, rather than composition, of the colour. The ratio of green/blue (Fig. 4) is almost constant over the entire range of pH, and is therefore of little or no value in determining the nature of the colour changes.

It is apparent from the curves in Fig. 2 that for meat from a given muscle there is a relation between pH and colour of pork, beef and mutton. The general shape of the pH-colour curves is the same for the three meats, and although it is not evident from Fig. 2, other experiments with pork and beef that gave curves quite similar to those shown, indicate that the pH for maximum scatter from these two meats varies between 5.0 and 5.5. There seems,

then, to be no essential difference in the pH-colour relations for pork and beef, and it is not unlikely that the similarity applies also to mutton, although this should not be definitely concluded from the single experiment.

Four curves for unminced pork, similar to the one shown in Fig. 2, were obtained with samples from the corresponding leg muscles of different animals. The data showed that the amount of scatter at the same pH may differ for different animals by an amount comparable with the change in scatter brought about by alteration of pH in material from a single animal over the entire range investigated. It is therefore evident that factors other than pH are equally or possibly more important in determining the colour of fresh meat from a given animal. Nevertheless, if average values for a sufficient number of samples at each pH are plotted, as in Fig. 3, the relation between pH and colour can be observed with material from different animals.

Acknowledgment

The author wishes to acknowledge the valuable technical assistance of Mr. E. A. Rooke, Laboratory Assistant, National Research Laboratories.

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TENDERNESS OF MEAT: I. A RECORDING APPARATUS FOR ITS ESTIMATION, AND RELATION BETWEEN pH AND TENDERNESS[1]

By C. A. Winkler[2]

Abstract

A recording apparatus for estimating tenderness of meat is described. Samples of approximately equal cross section are cut between blunt jaws brought together by a constantly increasing force. The movement of the jaws is recorded on a drum revolving at constant rate, producing a curve on which the co-ordinates of any point can be interpreted in terms of the thickness of sample cut by a given force. By measuring the areas beneath the curves, and applying a correction for variations in initial thickness of the samples, comparative values for the work required to cut the samples can be obtained. The standard deviation of the mean of duplicate determinations on a single sample is ± 3%.

The relation between pH and tenderness was investigated by using samples of pork from three animals and adjusting the pH by injections of lactic acid or ammonia solutions. Toughness was at a maximum at pH about 5.0–6.0; at higher or lower pH levels the meat became progressively more tender. Studies with beef gave similar results, but there was some indication that maximum toughness occurs at a somewhat lower pH. Between different animals the pH at which maximum toughness occurred was more variable in beef than in pork.

Introduction

As tenderness is one of the most important characteristics of good quality meat, it is being studied in these laboratories as part of the investigations into the storage and transport of meat. Of the factors affecting tenderness, those that have received the most attention from other workers are: position in carcass (2, 4, 5, 8), collagen content (2–5), freezing (2, 8, 9) and storage (1, 2, 6, 9). Both subjective and objective methods have been used for estimating tenderness, and arguments have been advanced in support of both procedures (6, 8). For routine measurements, however, an objective method is almost essential, owing to the difficulty of establishing a panel of suitable judges that would be available as required. An apparatus combining simplicity of design (2) with the advantages of a recording device (10) has therefore been constructed for estimating tenderness.

Apparatus and Method

A diagram of the recording apparatus is shown in Fig. 1. The sample of meat is placed between the fixed jaw *A* and the movable jaw *B*. The latter is attached to the duralumin lever *C*, which is counterbalanced by the weight *W*. The upper jaw is held by two metal plates between which the lower jaw moves with about 1 mm. clearance on each side. When the slide *F* is pushed to one side in its groove, fine lead shot runs from the hopper *D* into the aluminium pan *E*. A round hole in the slide controls the rate of flow

[1] *Manuscript received November 16, 1938.*

Contribution from the Division of Biology and Agriculture, National Research Laboratories, Ottawa. Issued as paper No. 16 of the Canadian Committee on Storage and Transport of Food.

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of the shot. As the weight of the shot is applied to the lever, the movable jaw approaches the fixed jaw, crushing the meat between them. At the same time, the pen *G* attached to the lever moves downward over a piece of graph paper fastened around the three-inch diameter drum *H*. The drum is geared to a "telechron" motor, which is started simultaneously with the flow of lead shot. This is accomplished by attaching the switch *K* to the slide *F* so that when the slide is opened the switch is closed, and *vice versa*.

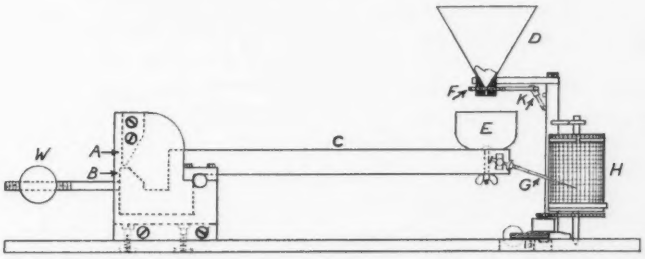

FIG. 1. *Diagram of apparatus.*

The jaws are similar to those described by Volodkevich (10), and are somewhat blunt, rather than sharp. Their action in severing the sample is presumably similar to that of teeth making a single bite.

To obtain curves convenient for subsequent analysis, the speed of rotation of the recorder drum and the rate of flow of lead shot from the hopper are adjusted to meet the requirements of the material being studied. For beef, pork and bacon it has been found satisfactory to use a rate of flow of shot of about 35 gm. per second, and a drum speed of about one revolution in four minutes. The rate of flow of the shot is constant within $\pm$ 0.5 gm. per second. With lubrication of the bearing by which the lever is mounted, and accurate adjustment of the counterweight, a weight of 3 to 5 gm. is sufficient to move the lever from a resting position. The errors from variation in rate of flow of the shot and from starting friction are negligible in comparison with sampling errors.

The sample of meat to be tested is trimmed to a length of about 4 cm., a thickness of approximately 1 cm. and such a width (about 1.5 cm.) that it fits snugly between the plates on either side of the jaws. Experiments have shown that the width can be 2 to 3 mm. less than the distance between the limiting plates without detectable error, probably because the meat is spread against the plates almost as soon as the cutting action of the jaws begins. The sample is so prepared and inserted between the jaws that it is cut transversely to the direction in which the fibre bundles lie, *i.e.*, across the "grain" of the meat. Care is taken to avoid obvious striations of connective tissue.

As the weight of the lead shot on the lever increases, and the sample is crushed between the jaws, the pen moves downward over the chart on the

revolving drum to trace a curve similar to those shown in Fig. 2. Each pair of curves in the figure represent duplicate determinations on samples of meat from the same muscle of pork or beef. The co-ordinates of a point on such a curve are determined by the amount the pen has moved downward, *i.e.*, by the amount the lower jaw has approached the fixed jaw, and by the length of time the drum has revolved, from which the force acting to cut the sample can be calculated. Duplicate curves for each sample are started at a common point (*a*, Fig. 2), by adjusting the initial position of the pen. The end points (*b*, Fig. 2) of the curves, *i.e.*, when the jaws are together, will therefore differ by the amount the pen was adjusted to have the curves start at the same point,

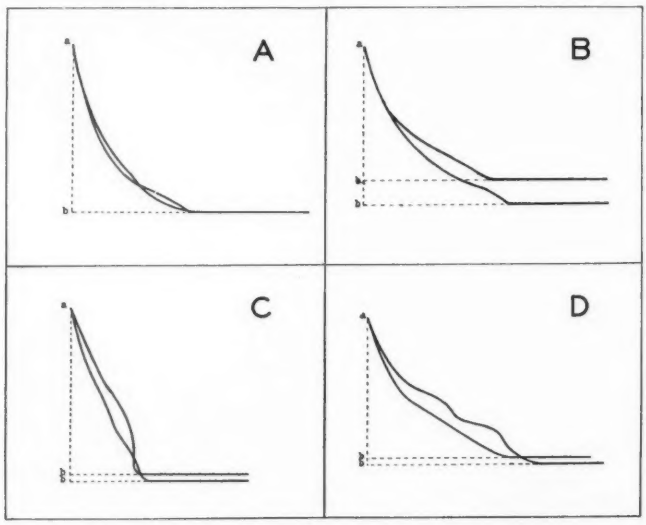

FIG. 2. *Typical curves obtained with the apparatus.*

and the difference between the end points is therefore a measure of the difference in initial thickness of the samples. For example, in *A*, Fig. 2, the duplicate samples were the same thickness, while in *B*, *C*, and *D* they were of different thickness. With the present apparatus there is a slight residual slope at the end point due to flex in the apparatus, but the residual slope is easily identified and seldom interferes with determination of the true end point. If, as with some samples, the curve approaches the end point very gradually, the constant residual slope can be extrapolated back to the point of intersection with the curve in order to obtain the true end point. This is seldom necessary as the error in determining the end point is negligible in comparison with sampling errors.

When the constants of the apparatus are known, the force necessary at the jaws to cut through the sample of meat placed between them can be

calculated. The necessary constants are the rate of flow of lead shot into the aluminium pan on the lever, the rate of revolution of the drum carrying the chart, and the ratio of the lengths of the lever arms. For most investigations, however, comparative values of the cutting force are adequate, and the method adopted for expressing the results has therefore been to estimate, with a planimeter, the area in square inches between the curve and two lines, one drawn along the ordinate axis from the starting point, the other drawn along the abscissa axis at the end point. For a given curve, this area will represent the work done in cutting through a sample, the thickness of which is represented by the ordinate distance from the starting point to the end point. To compare different curves on the basis of work done, all work values must be expressed for unit thickness of sample. Let area A under the curve for a given sample correspond to an ordinate distance d (representing the thickness of the sample), and assume that d_1 is the arbitrarily selected ordinate distance representing unit thickness of sample for which the work is to be calculated. Then the work done in cutting unit thickness of the given sample will be $\frac{d_1}{d} \cdot A$.

Experiments have demonstrated the validity of this method of correcting all work values to correspond to constant thickness of sample, providing the differences in thickness are not too great. The standard deviation of the mean of duplicate determinations calculated from 20 pairs having mean values varying from 0.8 to 4.6 was $\pm$ 0.05 for samples carefully selected to be free from connective tissue, and varying in thickness by not more than $\pm$ 20%. With some practice it is not difficult to cut the samples to a thickness within about half this tolerance. The precision with which tenderness may be estimated by the method is well within the limits of accuracy imposed by sampling errors.

The general shape of a curve obtained with the apparatus is often informative. A rapid change in the slope of a curve (upper curve, Fig. 2*C*) indicates a "critical" point, at which the force applied suddenly shears resistant fibres. It sometimes happens that more than one rapid change of slope shows on the curve, indicating more than one type of fibre. This is illustrated by the upper curve in Fig. 2*D*; it is interesting to note that although the samples used to obtain both the upper and lower curve were taken from the same muscle, only the sample corresponding to the upper curve showed heterogeneity of fibre type. The relative positions of the rapid changes in slope indicate the relative toughness of the different types of fibre.

Experimental Results

Samples of raw leg of pork and loin beef were adjusted to different pH values by injections of lactic acid or ammonia solutions of appropriate concentrations (7). Each sample weighed about 200 gm. and was given 8 to 10 injections of 1 ml., each distributed as evenly as possible throughout its mass. The samples were stored at 0° C. for four days, after which two sub-samples

were cut from each for tenderness measurements. Hydrogen ion concentration was measured on the sub-samples with a glass electrode.

The results of three experiments with pork and beef, each experiment being made with meat from different animals, are shown graphically in Fig. 3. Each point on a curve represents the mean of two determinations, made on different sub-samples from the same sample; the standard deviation of the mean is ± 0.15 for loin beef and ± 0.23 for pork, calculated from 21 and 30 pairs of duplicates having mean values varying from 1.0 to 3.4 and 1.3 to 3.6, respectively.

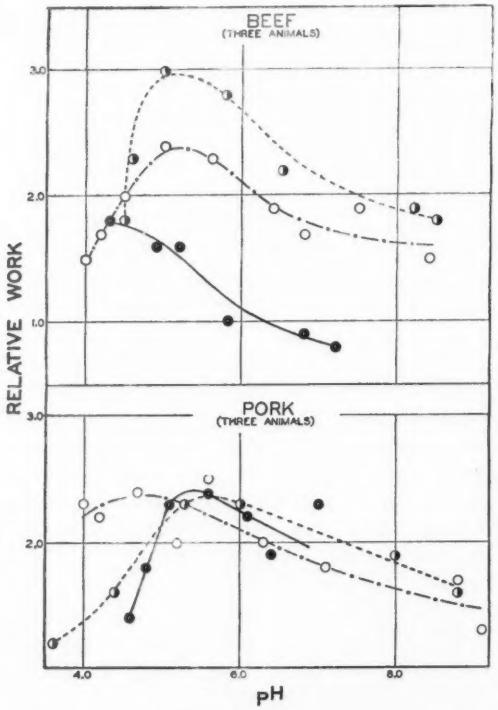

FIG. 3. *Relation between pH and tenderness for pork and beef.*

Discussion

The sampling error in these experiments is large in comparison with the precision of the method used for estimating tenderness. With the technique employed, there were three factors that might have contributed significantly to the sampling error, and should, therefore, be considered: (*i*) variability in initial tenderness of the samples from which the sub-samples for pH and tenderness measurements were taken; (*ii*) non-uniformity of pH throughout

the sub-sample; (*iii*) the presence of striations of connective tissue in the sub-samples.

The influence of the initial tenderness on the final tenderness after adjusting the pH was not studied. However, it will be noticed in Fig. 3 that for a single experiment the deviation of any experimental point from the curve is not greater than the standard error for duplicate determinations at a given pH, *i.e.*, for duplicate determinations on a single injected sample of meat. As there is no reason to suppose that the initial tenderness varied more within a sample than between samples, the main error is probably in taking the sub-samples, including the non-uniformity of pH. The variability in initial tenderness would therefore seem to have little or no effect on the results obtained after injection. This is not improbable, because the variations in initial tenderness of samples from a given muscle are not likely to be large.

Non-uniformity of pH is accounted for by the slow rate of diffusion of lactic acid or ammonia through the meat. It would not be reliable to estimate tenderness at the identical position at which pH was measured in the sub-sample, as insertion of the electrodes undoubtedly ruptures some of the tissue. An average value for the pH was therefore obtained from at least two determinations made beside the line along which the sample was cut. It is estimated that this average pH might differ by $\pm$ 0.03 pH from that along the line of cut.

The error that striations of connective tissue would introduce into an estimate of tenderness can usually be avoided with reasonable care in selecting the sub-sample. Occasionally, connective tissue though present is not visible until the sample is cut, and a spurious result is obtained. Two pairs of duplicate determinations were rejected on this account from 55 pairs made during the present investigation.

In general, the curves in Fig. 3 show that the addition of sufficient lactic acid or ammonia to raw pork or beef made the meat more tender. The failure of one curve for beef to show a maximum might be due to experimental error, or possibly the maximum toughness, *i.e.*, minimum tenderness, for the beef used was not attained. The results suggest that for samples at the same pH from different animals, there is a greater variability in tenderness of beef than of pork; the variability observed with beef is, in fact, greater than the change in tenderness brought about by changing the pH within the limits of about 5.5–6.5 generally observed in beef carcasses. There is also some indication that the pH of maximum toughness is lower for beef than pork. More work with both meats would be necessary, however, to determine whether the indicated differences in variability between animals and pH of maximum toughness are significant.

It is not possible to account for the results depicted in Fig. 3 without additional data to supplement the pH—tenderness measurements. It seems unlikely, from the nature of the curves, that hydrolysis of connective tissue around the fibre bundles is responsible, to more than a minor extent, for the observed changes in tenderness. The changes might be associated with

changes in protein-water relations or possibly with increased activity of protein-splitting enzymes.

Acknowledgment

The author wishes to acknowledge the valuable technical assistance of Mr. E. A. Rooke, Laboratory Assistant, National Research Laboratories.

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STUDIES WITH A DEFICIENT RATION FOR SHEEP[1]

I. EFFECT OF VARIOUS SUPPLEMENTS
II. EFFECT OF A COBALT SUPPLEMENT

By J. E. Bowstead[2] and J. P. Sackville[3]

Abstract

Sheep became unthrifty when fed non-leguminous hays and ground oats over a period of seven months. Numerous feed and mineral supplements were fed in an endeavour to prevent the development of the unthrifty symptoms as well as to determine the nutrient or nutrients lacking in the deficient ration. Pasture, calcium and phosphorus, cod liver oil, tankage, linseed meal, bran, and alfalfa meal, when fed as supplements, delayed the appearance of unthriftiness. The feeding of iron and copper proved detrimental. Wheat germ meal did not improve conditions. Alfalfa ash proved to be the best of all the supplements studied in the maintenance of normal thrift. The beneficial effect of alfalfa ash indicated that the deficiency of the non-leguminous ration that caused unthriftiness was one or more of the minerals that were present in the alfalfa hay.

When cobalt was fed as a supplement to a few ewes that had developed the characteristic symptoms of unthriftiness, there followed a rapid increase in weight and improvement in thrift. Chemical analyses of various hays, alfalfa ash, and soil showed that the non-leguminous hays contained only small quantities of cobalt, similar to the amounts contained in New Zealand grass that caused similar symptoms to develop. Alfalfa hay grown on similar soil contained relatively large amounts of cobalt, whereas alfalfa hay grown in the Lethbridge district contained only small amounts of cobalt. The writers suggest that a cobalt problem may exist in Western Canada.

I. EFFECT OF VARIOUS SUPPLEMENTS

Introduction

In the last of a series of experiments conducted to determine the extent to which wool growth and quality were affected by certain nutritional and climatic factors (9, 11), there developed among the animals of the nutritional groups symptoms of extreme unthriftiness. The unthrifty condition of the ewes developed among animals fed a liberal ration of oat and prairie hays and ground oats for a period of more than seven months.

The ewes on this ration developed anorexia, lost weight, became anaemic, weak, and 12 out of 16 either died or had to be removed from the ration because of their extreme unthriftiness. In previous years when the same or similar rations had been fed during normal winter periods, no undesirable symptoms developed. Subsequent experience with this and similar rations has proved that the undesirable symptoms develop only after the animals have been fed these rations for long periods.

The recovery of the ewes when fed the usual flock ration containing some leguminous hays and feed supplements suggested that the undesirable symptoms had developed as a result of some nutritional deficiency. The fact that the feeds in the deficient ration were the most common sheep feeds, and the fact that the same symptoms are reported to develop in range sheep following

[1] *Contribution from the Department of Animal Husbandry, University of Alberta, Edmonton, with financial assistance from the National Research Council of Canada.*

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[3] *Professor of Animal Husbandry, University of Alberta.*

prolonged winter periods, made the problem of determining the deficiency of the ration of considerable practical importance.

Experimental Procedure

Two somewhat similar experiments were conducted, the first from January 1935 to May 1936, and the second from November 1936 to May 1938. During both trials one group of ewes was fed a basal ration similar to the one previously fed and believed to be nutritionally deficient. Other groups were fed the same basal ration plus certain supplements, which there was reason to believe might contain the nutrient or nutrients deficient in the basal ration. In each trial also there was one group of ewes fed a ration of alfalfa hay plus ground oats.

The rations fed were as follows:—

1st trial Jan. 1935 – May 1936	2nd trial Nov. 1936 – May 1938
Lot 1. Basal ration (non-leguminous hays and oats).	Lot 1. Basal ration (non-leguminous hays and oats).
2. Basal ration plus pasture.	2. Basal ration plus wheat germ meal.
3. Basal ration plus Ca and P supplements.	3. Basal ration plus linseed meal, wheat bran and tankage.
4. Basal ration plus Ca, P, Fe, and Cu supplements.	4. Basal ration plus alfalfa meal.
5. Basal ration plus Ca, P and cod liver oil supplements.	5. Basal ration plus alfalfa ash.
6. Alfalfa hay and oats.	6. Alfalfa hay and oats.

The hays were fed *ad lib.* The ewes were not forced to consume all of the oat hay allowance, the coarser and more unpalatable portions being considered as unavoidable waste. No hay wastage was allowed for alfalfa, while a very small wastage was allowed for non-leguminous grass hays.

The ground oats, as well as the oat and supplement mixtures, were fed in equal quantities to all lots. The concentrate allowance was increased during the suckling period; it was also increased to those groups losing weight and not consuming normal quantities of roughage.

All ewes were started on test after they had become nutritionally uniform on pasture and then on a common non-leguminous ration for a short period. All ewes remained on their experimental feed till they had been sheared and lambed 18 or 19 months after the trial commenced, or until they were removed from the experiment because of extreme unthriftiness.

Data were obtained on weight, feed consumption, reproduction, wool and any abnormal performance of the ewes.

Results

Graphs of Figs. 1 and 2 show the weights of the individual ewes during the first and second trials respectively. Average reproduction data are shown in Table I. The results for each group are discussed separately.

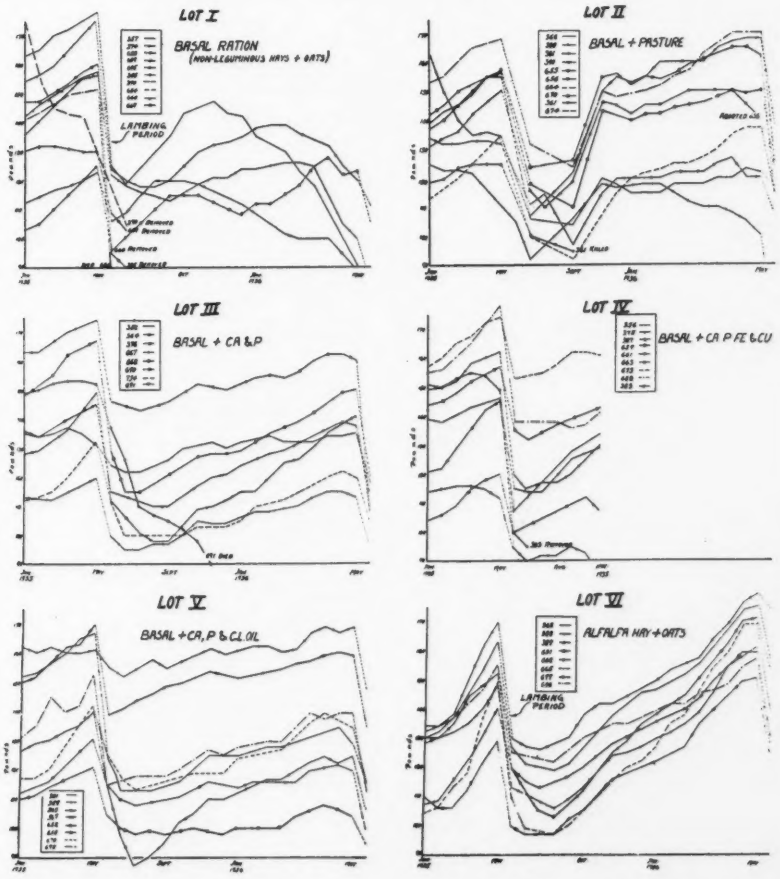

FIG. 1. *Graphs showing changes in weight of ewes during 1935–1936.*

Basal Ration

Oat and timothy hays plus ½ lb. ground oats daily were fed throughout most of the trial. In the first trial five of the ten ewes that began the trial either died or had to be removed from the experiment before seven months had elapsed. These five ewes weighed an average of 47 lb. less at the time of death or removal than they did at the commencement of the trial. The

five remaining ewes continued on the experimental ration till they had lambed after being on test for about 17 months. Four of these ewes had lost an average of 45.1 lb., while one gained 2.3 lb.

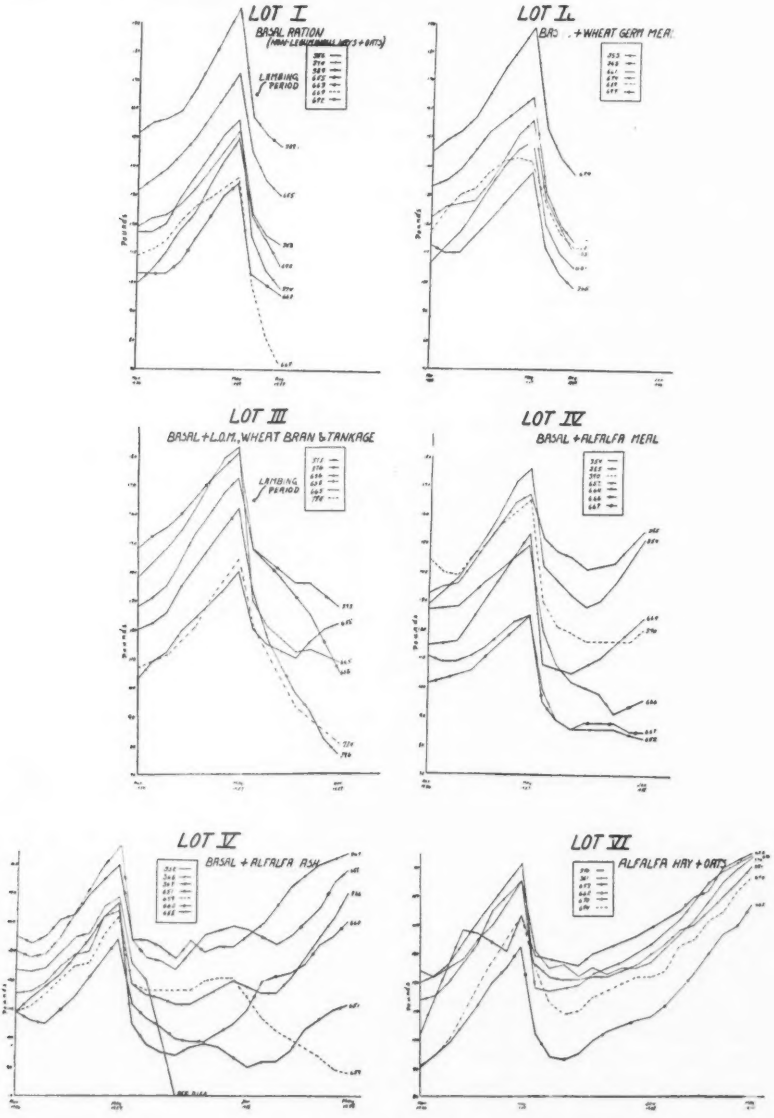

FIG. 2. *Graphs showing changes in weight of ewes during 1936–1938.*

TABLE I

REPRODUCTION DATA, 1935–1936 AND 1936–1938 EXPERIMENTS

Lot No.	Ration and supplement	Number of ewes						Vitality at birth			Per cent of living lambs	
		Bred	Withdrawn	Died	Aborted	Lambed	No. lambs dropped	Strong, %	Weak, %	Dead, %	Died, %	Weaned, %
1935 Lambing data					1935–1936							
I	Basal	10	3*	2*		9	13	69	23	8	67	33
II	Basal + pasture	10				10	16	81	6	13	46	54
III	Basal + Ca and P	8		1*		8	10	80		20	25	75
IV	Basal + Ca and P and Fe	9		1*	1	8	13	31	46	23	70	30
V	Basal + Ca and P and CLO	9				7	10	80	10	10	44	56
VI	Alfalfa hay	8				8	12	92		8	18	82
1936 Lambing data												
I	Basal	5				3	4	25	75		75	25
II	Basal + pasture	10	1*		1	9	12	67	25	8	27	73
III	Basal + Ca and P	7				7	9	100				100
IV	Basal + Ca and P and Fe	**										
V	Basal + Ca and P and CLO	9		1		8	12	75	17	8	9	91
VI	Alfalfa hay	8				8	14	100				100

**After lambing.*

***Discontinued.*

(Continued on Page 20)

TABLE I—*Concluded*

REPRODUCTION DATA, 1935–1936 AND 1936–1938 EXPERIMENTS—*Concluded*

Lot No.	Ration and supplement	Number of ewes						Vitality at birth			Per cent of living lambs	
		Bred	With-drawn	Died	Aborted	Lambed	No. lambs dropped	Strong, %	Weak, %	Dead, %	Died, %	Weaned, %
1937 Lambing data					1936–38							
I	Basal	7	7*			7	12	100			75	25
II	Basal + wheat germ meal	7	7*			6	9	89	11		67	33
III	Basal + tankage, etc.	7	7*			7	8	100			25	75
IV	Basal + alfalfa meal	7	7*			7	10	100			30	70
V	Basal + alfalfa ash	7				7	10	75	25		30	70
VI	Alfalfa hay	7				7	13	85	15		16	84
1938 Lambing data												
I	Basal	**										
II	Basal + wheat germ meal	**										
III	Basal + tankage, etc.	**										
IV	Basal + alfalfa meal	**										
V	Basal + alfalfa ash	7		1	1	5	6	100				100
VI	Alfalfa hay					6	13	92		8	17	83

* *After lambing.*
** *Discontinued.*

In the second trial the ewes developed the characteristic unthrifty symptoms after eight months of experimental feeding, and all were removed from the trial after nine months on test. While these ewes lost an average of only 13.8 lb., 9 of their 12 lambs born alive and strong had died from apparent malnutrition.

The results from these two groups fed the basal ration indicate that some deficiency existed to account for the failure to maintain thrift and normal reproductive ability.

Basal Ration during the Dry Feeding Period and Pasture during the Summer

Because the ewes became unthrifty only after a prolonged feeding of the basal ration, it was believed that green grass probably contained the nutrients deficient in the basal ration. In the first trial, after the ewes had been fed the basal ration from November 8, 1934 till May 24, 1935, the group was divided into two uniform groups. One group continued on the basal diet, whereas the other group was turned on to a non-leguminous pasture till November 15, 1935, when they were returned to the basal diet. The experiment ended in May 1936 after the ewes had lambed and were sheared.

The pasture proved beneficial. One ewe had to be killed as a result of a leg injury, but nine ewes completed the trial. One of these aborted and the remaining eight lost an average of over 19 lb.

The lambs dropped by the ewes at the end of the trial were much stronger than those dropped by the ewes on the basal diet, but were weaker than the lambs from the ewes receiving the dry supplements or alfalfa.

The 1936 fleece weights were also heavier for the ewes that had pastured in 1935 as compared to those receiving no pasture. The ewes fed alfalfa hay, however, yielded the heavier and stronger fleeces.

The beneficial effect of the non-leguminous pasture indicated that it provided some nutrient or nutrients lacking in the basal ration. The results, however, indicated that this pasture did not provide all the nutrients that were deficient in the basal diet as the ewes on alfalfa hay made better gains, produced stronger lambs, and yielded stronger fleeces.

Calcium and Phosphorus Supplements

Seven of the eight ewes remained on test during the entire 17-month period. The seven ewes lost an average of 18 lb. during the trial. The ewe that died lost 71.3 lb. in the 10 months on test. The nine lambs dropped by the ewes were strong and all successfully weaned. Calcium and phosphorus apparently caused a beneficial effect in preventing extreme unthriftiness and maintaining reproductive ability, if the results are compared to those secured from the group fed the basal ration. The results indicate that the basal ration must have been deficient in these minerals. Additional deficiencies of the ration are, however, indicated when the performance of the ewes fed the basal plus mineral ration is compared with the performance of the ewes fed alfalfa hay, as significantly better growth, reproduction, and thrift are shown by the latter group.

Cod Liver Oil

As the unthrifty symptoms that developed in the ewes on the basal ration might possibly have been due to a vitamin A or D deficiency, a group of ewes was given 10 cc. of (1% free acid) Poultry Cod Liver Oil twice weekly in addition to the calcium and phosphorus supplements. One ewe died after 13 months on test. The remaining eight ewes in this lot lost an average of 15.6 lb. while on test, compared to 18 lb. for those ewes not fed the cod liver oil. The eight ewes in this lot dropped 12 lambs in 1936, 11 of which were raised to weaning age. The slight beneficial effects of cod liver oil was not significant, indicating that the deficiency of the basal diet was not either of the vitamins contained in the cod liver oil.

Iron and Copper Supplements

Weekly doses of 0.35 gm. of iron and 0.07 gm. of copper in the form of iron chloride and copper sulphate were fed in addition to the basal ration and calcium and phosphorus supplements. Deleterious effects began to be noted after five months on test. One ewe aborted at that time. One ewe died in less than seven months. While the remaining seven ewes lost an average of only 3 lb., their lamb crop was adversely affected. Of the 13 lambs dropped in 1935 by the eight ewes, 3 were born dead, 7 died soon after birth, and only 3 survived to five months of age. Seven of the nine fleeces were graded as tender, while only one fleece was graded tender in the lot not fed the iron and copper supplements. The deleterious effects may have been due to a poisonous effect of an excess of iron or copper as indicated by the reports of Deobald and Elvehjem (6) and Broughton and Hardy (5).

The results obtained by the feeding of calcium, phosphorus, iron and copper, and vitamins A and D in the cod liver oil suggested that while some beneficial effects were obtained with the calcium and phosphorus, a deficiency was still apparent. The 1936–1938 trial was outlined to find if possible a feed supplement that would provide the apparent deficiency of the basal ration, and indirectly lead to the discovery of the specific deficient nutrient or nutrients.

Wheat Germ Meal

Wheat germ meal was used as a supplement to the basal ration because the complex of life-promoting substances contained in the germ of seeds would possibly include the deficient nutrient. A $\frac{1}{2}$-lb. portion of a mixture of 60% ground oats and 40% wheat germ meal was fed throughout the trial. No beneficial effect was noted. The ewes fed on wheat germ meal lost an average of 13.7 lb., while those on the basal ration lost 13.8 lb. Six of the nine lambs dropped by the ewes on wheat germ meal died before weaning, while nine of the twelve dropped by the ewes on the basal ration died. Both the group on wheat germ meal and that on the basal ration were discontinued on August 14 because of their apparent unthrifty condition and loss of lambs.

Linseed Meal, Tankage, and Wheat Bran

Linseed meal and tankage were fed as conditioners or as tonics and to provide, if present, the deficient nutrient of the basal ration. The ewes con-

sumed ½ lb. of a concentrate mixture of 80% oats, 10% linseed meal and 10% tankage with apparent relish for about eight months. After that time, however, the ewes ate their concentrate mixture less rapidly, and after nine months of experimentation it was deemed necessary to replace the tankage with wheat bran to encourage the ewes to eat the ½ lb. daily concentrate allowance. The appetite was not improved by removing the tankage nor by adding wheat bran to the concentrate mixture, the ewes showing increased symptoms of anorexia. After 13 months of experimentation it was necessary to remove the ewes from the trial because of their continued decline in weight and thrift. At that time one ewe had been removed, five ewes had lost an average of 30 lb., and one ewe made a gain in weight of 23.5 lb. The seven ewes produced eight lambs, six of which were raised to weaning age.

While some benefit was derived from the feeding of linseed meal, tankage, and later wheat bran, as shown by the maintenance of weight and thrift for a longer period of time, the development of anorexia and extreme unthriftiness suggests that some important nutrient or nutrients were still lacking in the ration.

Alfalfa Meal

The recovery of the afflicted ewes, when placed on a ration containing alfalfa hay and oats, suggested that alfalfa hay contained the nutrient or nutrients deficient in the basal and other non-leguminous rations. A 0·6-lb. portion of a mixture of equal parts alfalfa meal and oats was fed daily to the ewes to determine whether this amount of alfalfa would contain sufficient of the missing nutrient or nutrients to prevent the development of the unthrifty symptoms. The 0.3 lb. of alfalfa meal was equal to $\frac{1}{10}$ the amount of alfalfa hay fed to the ewes receiving this hay and oats.

The ewes in this group continued to grow and reproduce normally for eight months before four of the seven began to decline slowly in weight. These four ewes lost an average of 36.2 lb. during the 14 months on test, at which time they had to be removed from the trial. At the end of the 14-month period the three remaining ewes had gained an average of 15.5 lb. and appeared normal in flesh and thrift.

The facts that the ewes on the basal ration were removed from the trial at the end of a 9-month feeding period, and that the ewes fed the alfalfa meal supplement remained thrifty and continued on trial for 14 months, were evidence of the beneficial effect of alfalfa meal. However, as the unthrifty symptoms finally developed, alfalfa meal did not completely provide the necessary nutrients, probably as a result of the small amounts of alfalfa meal actually consumed.

Alfalfa Ash

The question arose as to whether the beneficial effect of alfalfa hay in preventing unthriftiness was due to its mineral or non-mineral constituents. To answer that question a group of seven ewes was fed the basal ration with alfalfa ash added. The concentrate mixture fed to these ewes was 80%

ground oats and 20% alfalfa ash. In the ½-lb. portion fed daily, the ewes consumed the equivalent of ash contained in 1 lb. of alfalfa hay, or ⅓ the amount consumed by a group of ewes receiving alfalfa hay and oats as their ration. During the latter months the percentage of ash in the concentrate mixture was reduced to 15% to prevent wastage. Increased amounts of this mixture were fed daily.

None of the ewes receiving alfalfa ash developed the characteristic unthrifty symptoms, and all continued on trial till they had lambed, 19 months after the beginning of the trial. While one ewe died following a short illness after a 10-month period, and one aborted after 16 months on test, the remaining five ewes maintained their weight and thrift. No reason for the death or abortion could be determined. The death of ewes in other groups due presumably to a nutritional deficiency occurred only after a long period of decline. As no abortions occurred in the other groups fed less adequate rations, the abortion recorded in this group is regarded as not being due to the ration fed.

The five ewes produced strong lambs at birth and yielded fleeces that were uniformly good, whereas ewes that developed the characteristic symptoms failed to produce thrifty lambs or to yield fleeces that were strong.

The beneficial effect of the alfalfa ash indicated that the nutrient or nutrients lacking in the basal ration and contained in alfalfa hay is or are minerals that remained in the alfalfa ash.

Alfalfa Hay and Oats Ration

Because the ewes that developed unthrifty symptoms on the basal and other non-leguminous ration recovered when transferred to the alfalfa hay flock ration, it was thought advisable to carry one group of ewes on a ration of alfalfa hay and oats for comparative purposes. While the basal ration was regarded as deficient, the alfalfa-oat ration was considered to be complete. The ewes were forced to eat all the alfalfa fed and received ½ lb. of ground oats daily except during the period of heaviest suckling when more concentrates were fed.

The ewes actually gained in weight in both the 1934–1936 and the 1936–1938 trials, and produced large and thrifty lamb crops with a lower mortality than any other lot. The eight ewes in the first trial gained an average of 14.2 lb. and the six in the second an average of 17.8 lb.

Alfalfa hay proved to be the most complete of the rations fed. While the ration containing alfalfa ash gave good results, the ewes failed to make the gains of those fed alfalfa hay, no doubt owing to the fact that they received ash derived from only 1 lb. of alfalfa hay.

II. EFFECT OF A COBALT SUPPLEMENT

Introduction

The 1936–1938 experiment (reported in Part I) gave evidence that the deficiency of the non-leguminous hay and oat ration that caused the development of the anorexia and unthrifty symptoms was in the ash portion of alfalfa hay.

The mineral or minerals involved were not indicated by the results as no detailed chemical analyses of the feeds or feed supplements were made.

Toward the close of the above mentioned trial several papers were published that suggested that cobalt might be the mineral that was deficient in the basal ration fed in the trials previously reported. Neal and Ahmann (10), in their experiments with calves in Florida, reported that calves developed anorexia and became unthrifty and anaemic on a ration of Natal grass, corn, skim milk powder, cod liver oil and whole milk. The condition was "prevented or cured by cobalt supplementation and was aggravated by the use of iron and copper supplement." Askew and Dixon (1) reported that the results of their experiments with sheep "definitely suggest that bush-sickness is caused by a mineral deficiency and that cobalt, so potent in overcoming the ailment, is probably present in deficient supply."

Experimental Procedure

At the time it was decided to study the effect of cobalt as a supplement to the basal ration, animals suitable for the study were few.

In the lot receiving the basal ration plus alfalfa meal, four of the seven ewes had developed the characteristic symptoms and had lost an average of 36.2 lb. These four ewes were, therefore, used in the cobalt supplement study.

The group of ewes that was fed the basal ration plus linseed meal, tankage, and wheat bran, had to be removed from their experimental ration 13 months after the trial began, because one ewe had died and five had lost an average of 30 lb. in weight. One ewe had gained in weight. These particular ewes had been fed a mixture of equal parts alfalfa and timothy hays together with oats for one month previous to placing three of them on the basal ration as controls and the remaining three on the same ration plus cobalt.

Five mgm. of cobalt in the form of the chloride in solution was given to each of the ewes daily, as a drench.

Cobalt determinations were made on the hays that had been fed, and upon the alfalfa ash. In order to compare the cobalt content of similar feeds grown in other parts of the province, two samples of other hays were secured from Lethbridge for analysis.

Results

The accompanying charts (Fig. 3) show the increase in weight that followed the administration of cobalt to the ewes.

The four ewes that had been fed the basal ration plus alfalfa meal, and that had developed anorexia and were unthrifty, gave an almost immediate response when cobalt was fed. Between December 31 and prior to lambing (approximately May 20), these ewes made an average gain of over 43 lb. The ewes exhibited increased appetites, appeared thriftier, and dropped strong and well-developed lambs, but their fleeces showed a weakness in the centre of the fibres.

It will be noted by comparing the growth charts in Part I that no group of ewes showed as rapid gains in weight as did these four ewes fed cobalt. The

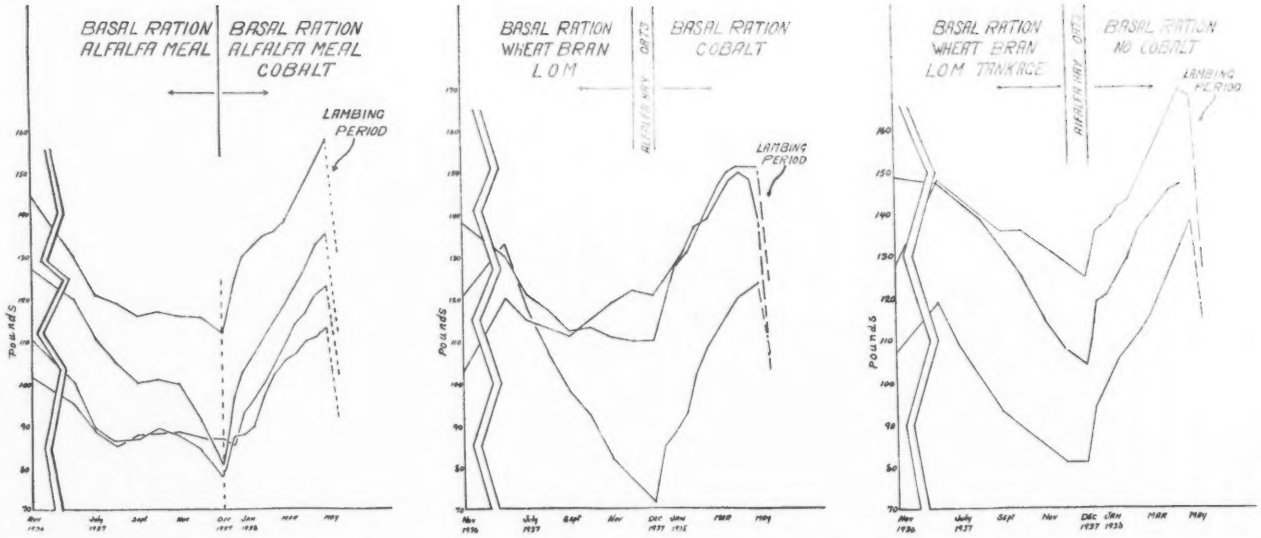

FIG. 3. *Graphs showing changes in weight of ewes prior to and after cobalt feeding.*

groups of ewes fed alfalfa hay or alfalfa ash supplement gained steadily between December and May but not as rapidly as those receiving cobalt.

The fact that there was no change in the ration in kind and amount prior to and after cobalt was fed, strongly suggests that the recovery of the ewes was due to the cobalt.

The three ewes that had been fed the basal ration plus linseed meal, tankage and wheat bran during 13 months of the trial, followed by one month of alfalfa feeding, also made rapid gains in weight when placed on the basal ration plus cobalt. The fact that the other three ewes in the same lot not receiving cobalt likewise made rapid gains suggests that the gains made by both groups of three ewes may have been caused by the alfalfa hay fed during the month previous and not by the cobalt.

The rapid gains of the three ewes not receiving cobalt may also have been due to consumption of the faeces of the ewes receiving cobalt.

Askew and Josland (3) found in their experiments on the rate of excretion of cobalt by sheep after drenching with similar amounts of cobalt that "practically the whole of the ingested cobalt can be recovered," that "only 2% of the cobalt in the drench appeared in the urine, the remainder, beyond an undetermined amount stored in the organs, being excreted in the faeces." Therefore, as the cobalt requirement is extremely small, and the greater quantity of the amounts fed is excreted in the faeces, the three ewes not fed cobalt may have secured sufficient from the faeces of the ewes receiving cobalt.

Chemical analyses of feeds and soil were made to explain, if possible, the results obtained.

The oat, timothy, and alfalfa hays, as well as the ash used in the 1936–1938 trial were analyzed for cobalt by the Provincial Analyst using the method reported by Kidson, Askew and Dixon (8). The cobalt in parts per million was as follows:

Oat hay	Nil
Timothy hay	.02
Alfalfa hay No. 1	.16
Alfalfa hay No. 2	.16
Alfalfa ash (from alfalfa hay No. 2)	2.00
Alfalfa ash (clinkers from alfalfa hay No. 1)	1.00

The above hays were grown on the University Farm or on similar soil in the surrounding district. The soil upon which Alfalfa hay No. 2 was grown contained 3.40 parts per million of cobalt.

Samples of alfalfa and timothy hays grown in the Lethbridge area were analyzed and the results were as follows:

Alfalfa hay	.012 parts per million
Timothy hay	Nil

Kidson (7) reports that in New Zealand soil, "bush sickness" in sheep occurs in districts where there is less than two parts per million of cobalt. Askew and Maunsell (4) report that in these districts the cobalt content of the pasture is much lower than in areas where bush sickness is not prevalent. Askew and Dixon (2) in their experiments found that legumes take up more cobalt than do the grasses.

The result of these trials and the analyses made suggest that the basal diet was deficient in cobalt. This is indicated by the low amounts of cobalt in the non-leguminous hays as well as by the response that the afflicted animals made to the feeding of cobalt. The superior performance of the ewes fed alfalfa hay was probably due to its higher cobalt content, as shown by its chemical analysis.

The low cobalt content of the Lethbridge alfalfa and timothy hays suggests that sheep in that part of Alberta may be receiving insufficient cobalt for the maintenance of normal growth and thrift.

Acknowledgment

The authors are indebted to Dr. G. Hunter and his associates in the Department of Biochemistry, University of Alberta, for their valuable assistance in connection with various phases of the work.

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